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CENTER FOR RADIATION RESEARCH

U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology

1990 Technical Activities

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NISTIR 4506

Center for Radiation Research

1990
Technical Activities

February, 1991

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Center for Radiation Research
National Measurement Laboratory

U.S. DEPARTMENT OF COMMERCE, Robert A. Mosbacher, Secretary
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ABSTRACT

This report summarizes research projects, measurement method development, calibration and testing, and data evaluation activities that were carried out during Fiscal Year 1990 in the NIST Center for Radiation Research. These activities fall in the areas of radiometric physics, radiation sources and instrumentation, and ionizing radiation.

Key Words: Ionizing radiation; measurement support; nuclear radiation; radiation instrumentation; radiation measurements; radiation sources; radiometric physics

INTRODUCTION

This report is a summary of the technical activities of the NIST Center for Radiation Research (CRR) for the period October 1, 1989 to September 30, 1990. During this period the Center was one of four Centers in the National Measurement Laboratory. On January 4, 1991 a reorganization plan was approved for NIST. A new Physics Laboratory will be formed from CRR and the Center for Atomic, Molecular, and Optical Physics.

The Center for Radiation Research develops and maintains the scientific competences and experimental facilities necessary to provide the Nation with a central basis for uniform physical measurements, measurement methodology, and measurement services in the areas of near infrared radiation, optical (visible) radiation, ultraviolet radiation, and ionizing radiation (x rays, gamma rays, electrons, neutrons, radioactivity, etc.); provides government, industry, and the academic community with essential calibrations for field radiation measurements needed in such applied areas as nuclear power, lighting, solar measurements, aerospace, defense, color and appearance, health care, radiation processing, advanced laser development, and radiation protection for public safety; carries out research in order to develop improved radiation standards, new radiation measurement technology, and improved understanding of atomic, molecular, and ionizing radiation processes, and to elucidate the interaction of radiation and particles (electrons, neutrons, and ions) with inanimate and biological materials; and participates in collaborative efforts with other NIST centers in the interdisciplinary applications of radiation.

This report summarizes the activities that were carried out by the three divisions that comprised the Center for Radiation Research (CRR) for fiscal year 1990. Specifically the three CRR units included the Radiometric Physics Division, the Radiation Source and Instrumentation Division, and the Ionizing Radiation Division. Each organizational unit tells its own story in its own way. In general there is an introduction followed by a series of short reports on current activities, publications during the year, talks given, committee participation, and professional interactions.

A detailed table of contents has been provided to permit the reader to find those activities of greatest interest. To obtain more information about particular work, the reader should address the individual scientists or their division, c/o Physics Laboratory, Physics Building, B160, National Institute of Standards and Technology, Gaithersburg, MD 20899.

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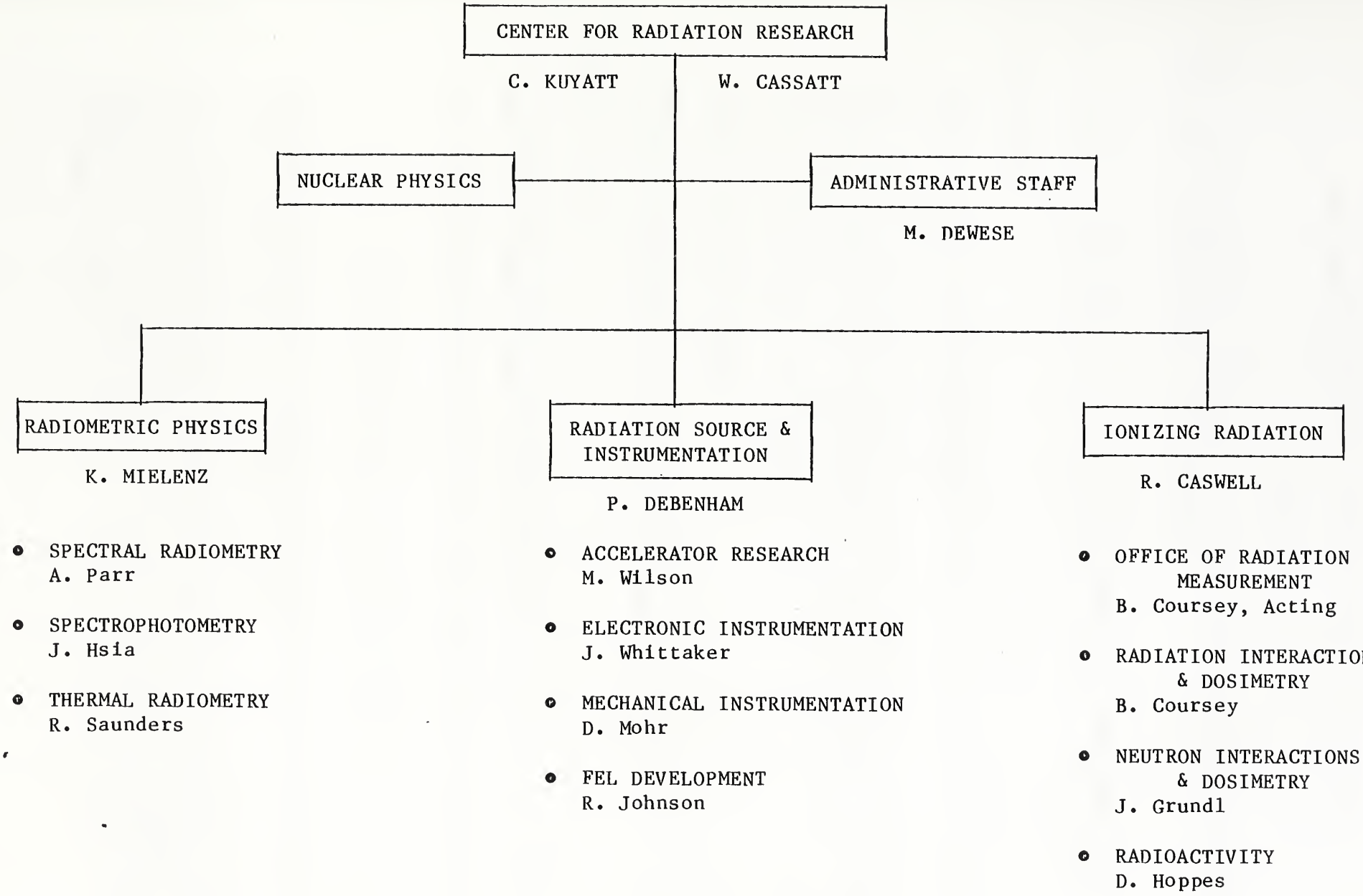
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SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

530, Center Office

Wayne Cassatt organized four workshops for prospective FEL users: "Properties of High-Power Fiber Optics in Biomedicine," "Raman Spectroscopy," "Time-Dependent Spectroscopy," and "Biomedical Applications of FEL's." January 1990.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Chris E. Kuyatt

Member, Council for Optical Radiation Measurements (CORM). Attended the Annual Meeting and Board Meeting, Rochester, May 1990.

NIST Liaison to the National Council on Radiation Protection and Measurements (NCRP). Prepared nominations for Council membership; arranged NIST attendance and attended the Annual Meeting, April 1990. Supervised review of several draft NCRP reports.

Chairman, NIST Radiation Safety Committee.

Member, NIST Patent Committee.

Member of a Technical Advisory Group for ISO/TAG4/WG3 which is preparing a "Guide to the Expression of Uncertainty." Have applied to be a member of the U.S. TAG.

Wayne A. Cassatt

Chairman, Subcommittee on Neutron and Nuclear Data Needs for the 1990's, Department of Energy/Nuclear Science Advisory Committee (NSAC).

SDI Meeting on Medical Applications of Free Electron Lasers, Naples, Florida, October 1990.

MAJOR CONSULTING AND ADVISORY SERVICES

Consultant to, Southeastern Universities Research Association (SURA) Committee on Special Projects. Attended SURA Board of Directors' Meeting.

Wayne Cassatt gave presentations and/or consulted on free electron laser applications to: Duke University, University of Alabama at Birmingham, North Carolina Central University, Vanderbilt University, Johns Hopkins University, NIH, University of Maryland at Baltimore, Charlotte Medical Center, Wake Forest University, University of Pennsylvania, Wellman Laboratories of Harvard University, MIT Bates Laboratory, and Stanford Synchrotron Radiation Laboratory. Fall 1989 to fall 1990.

TECHNICAL ACTIVITIES

Division 534, Radiometric Physics

Introduction

Mission

The Radiometric Physics Division (534) of the Center for Radiation Research is the primary unit within NIST for carrying out the basic mission of promoting accurate, meaningful, and compatible optical radiation measurements in the uv, visible, and ir spectral regions. The Division:

- develops, improves, and maintains the national standards for radiation thermometry, spectroradiometry, photometry, and spectrophotometry;
- disseminates these standards by providing measurement services to customers requiring calibrations of the highest accuracy;
- conducts fundamental and applied research to develop the scientific basis for future measurement services in optical radiometry.

Organization

The Division employs approximately 30 scientists, engineers, and technicians, and maintains a balanced mix of research, development, and measurement services. It is organized in three groups, and operates under a project structure with collaborations across group lines. Each of the projects has an assigned leader who is responsible for planning and accomplishing the technical objectives of the project. The project teams in the Division interact and work jointly on various tasks, sharing resources to achieve common goals. For example, the Detector Metrology Project in Group 534.01 works with most of the other projects in the Division to supply calibrated detectors for radiometric purposes. This project structure is sufficiently fluid to allow for redirection of resources to accomplish newly identified program goals and has proven to be a useful management tool for tracking progress and assigning responsibility.

The technical activities of the three groups in FY 1990 will be reviewed in this report on a project-by-project basis. The members of each project team will be named, the person listed first being the project leader.

Collaborations

In pursuing its goals, the Division is actively engaged in collaborative efforts with industry, other government agencies, universities, professional societies, and standards organizations. Its programs are developed in consultation with user groups at the national and international levels. Examples of these collaborations are listed below.

CORM. Among the constituents of the Division, the U.S. Council for Optical Radiation Measurements (CORM) is a paramount organization which aims at establishing a consensus among interested parties on industrial and academic requirements for physical standards, calibration services, and interlaboratory collaborations in the field of optical radiometry. In a 1989 report entitled "Pressing Problems and Projected National Needs in Optical Radiation Measurements," CORM has stated that the following radiometric and spectrophotometric projects should be undertaken on a priority basis:

Improved Standards of Spectral Radiance and Irradiance
Infrared Detector Standards
Radiometry: Measurement Procedure and Technique
Imaging Radiometry
Long-Wave Infrared Radiometry
Photometry: Improved Measurement Capability
Pulsed Radiometry
Laser-Beam Profile
SRM's for: Visible and Near-IR Reflectance Factor
IR Total Hemispherical Reflectance Factor
Visible and Near-IR BRDF
Visible High Transmission Density
Whiteness
Documentary Standards of Geometric Conditions in
Color Measurements

The Division has initiated work on several of these projects within the constraints of available resources and other programmatic commitments. Plans to implement the CORM proposals on a broader scale have been developed and submitted to NIST management with advice from the CORM Board of Directors.

Other Government Agencies. A significant portion of the Division's activities is devoted to standards development and measurement support for other agencies. The Department of Defense has funded the development of major measurement facilities in the Division for low-background, infrared radiometry and bidirectional scattering metrology. Collaborations with the Calibration Coordination Group (CCG) of DoD have continued during FY 1990 with emphasis on the following tasks:

Low-Background Infrared Standards
Ultraviolet Radiometry
Ambient-Background Infrared Detector Characterizations
Photodetector Transfer Standards
Bidirectional Reflectance of Optical Surfaces
Long-Wavelength Infrared Spectrophotometry.

The Division has provided measurement support to NASA and NOAA for space-borne radiometry, and is engaged in collaborations with EPA and NASA on terrestrial and extraterrestrial UV solar-irradiance measurements. The development of flammability standards for FAA is underway.

CCPR. The Division is the principal NIST member of the Consultative Committee for Photometry and Radiometry (CCPR), the committee which is responsible for coordinating world-wide activities in optical radiometry under the Treaty of the Meter. The CCPR held its 1986-1990 quadrennial meeting at the International Bureau of Weights and Measures in September 1990 and formed working groups to carry out the following activities during the 1990-1994 quadrennium:

Results of Spectral Irradiance Intercomparison. This intercomparison was conducted during the 1986-1990 quadrennium with the Division acting as the coordinating laboratory (see below). The report will be finalized by May 1991.

Air-Ultraviolet Radiometry. The CCPR recognized the need for better standards in this spectral region and appointed a working party to advise on future activities.

Spectral Responsivity Intercomparison. An international intercomparison of monochromator-based spectral responsivity measurements of silicon photodiodes will be planned for the 1994-1998 quadrennium.

Luminance Intercomparison. The availability of photopic filters will be studied in preparation for an intercomparison of detector-based luminance measurements during the 1994-1998 quadrennium.

Infrared Radiant Power Measurements. The CCPR will continue to maintain liaison with the body responsible for this area, the Consultative Committee on Electricity (CCE)

Supply of Standard Lamps. The activities of national laboratories are increasingly impeded by world-wide difficulties in obtaining standards-quality lamps having the necessary life, stability, and uniformity. The BIPM will examine this problem, and will collect experience and perform experiments in order to recommend lamps suitable for use in national laboratories for maintaining and comparing photometric and radiometric units.

Future BIPM Programs. The BIPM has established a laser-based detector characterization facility. A monochromator-based system will be added during the 1990-1994 quadrennium.

Members of the Radiometric Physics Division of NIST are represented on all of these working groups.

I. Spectral Radiometry Group (A. C. Parr, Leader)

This Group performs basic and applied research in spectral radiometry, photodetector metrology, photometry, and low-background infrared (LBIR) radiometry. The Group develops advanced standards, techniques, and facilities for these applications, and performs calibrations.

Detector Metrology Project (Cromer, Thomas, Houston)

Research and development in characterization of photodetectors is the primary focus of the efforts of this project. This includes the measurement of the absolute spectral responsivity, linearity, and spatial uniformity of detectors.

High-Accuracy Cryogenic Radiometer. In collaboration with the National Physical Laboratory (NPL) of the U.K., NIST has acquired and commissioned a high-accuracy cryogenic radiometer (HACR) which is capable of accuracies (3σ) of 0.01%. The HACR was tested by comparing it to a similar radiometer at NPL. The intercomparison was accomplished using a silicon-diode radiometer as the transfer device and showed agreement of 0.005% at two power levels. The HACR will serve as the primary NIST standard of photodetector spectral response.

Spectral Response Calibrations. The spectral response comparator has been upgraded to provide more efficient services. An improved detector/amplifier package based on the experience gained in the CCPR and CIE detector intercomparisons, will be used in the detector response intercomparison program (DRIP).

CIE Detector Intercomparison. In a follow-up to the recent CCPR detector response intercomparison, 15 U.S. and foreign industrial and academic laboratories participated in an intercomparison of silicon photodiode responsivity in the visible region. Two thirds of the laboratories reported values which agreed with NIST values to within +1% at 488 and 633 nm.

Trap Detectors. The arrangement of three or four diodes in a light-trapping configuration that minimizes reflection losses has been improved further. Depending on the diodes used, these devices can be used in narrow spectral ranges as absolute standards ("QED's") or in wider ranges as stable transfer standards.

Wedge-Window Radiometers. A new type of radiometer, consisting of a silicon diode hermetically sealed in dry nitrogen behind a wedged quartz window, has been developed. This avoids the interference effects found in commercial windowed diodes.

UV Detector Spectral Measurements. A monochromator-based facility for characterizing the uv response has been completed. The system features uv enhanced optics and a capability to determine spatial variations of response. The extension of the NIST spectral responsivity scale into the uv was accomplished with spectrally flat, thermal detectors.

IR Detector Spectral Measurements. The development of a detector characterization facility for the near and long-wave ir (to 30 μm) has started. The facility will employ dispersive or FT optics.

Detector Applications Project (Hardis, Larason, Eppeldauer, Houston)

The major thrust of this project is in applications of photodetectors to all aspects of radiometry and photometry which are responsibilities of the Division. The project includes photometric calibrations which are established on a detector base.

Changes in the NIST Candela and Lumen. The introduction of the new scales of thermal radiometry has resulted in a 0.35% increase in the photometric base units realized and maintained at NIST. This has reconciled small discrepancies that existed in the past. For example, the luminous-intensity data contributed by NIST to the 1986 CCPR candela intercomparison are within 0.1% of the world mean when adjusted to the 1990 scale.

Reciprocity Agreements. NIST has signed bilateral agreements which recognize the equivalence of the SI units of luminous intensity maintained by NIST and the national laboratories of Italy, France, and Canada. The 1986 CCPR candela intercomparison served as the basis for these agreements, which facilitate international trade.

New Photometry Laboratory. A modern laboratory for routine calibrations of luminous intensity, luminous flux, and color temperature is nearing completion.

Photopic Detectors. Realizations of the NIST candela by photopically-filtered silicon detectors are completed. A group of nine detector packages has been constructed, characterized, and compared with standard lamps. These detectors will supersede the blackbody-based NIST measurement base in photometry. The two scales are presently being intercompared and the photometric quantities in the future will rely upon the detector base.

Alternatives to Goniometry. Four miniature lamps were calibrated, first by traditional goniometry, and then in a specially configured sphere against a spectral irradiance standard located external to the sphere. The agreement between the two methods was on the order of 0.5%. This demonstrated the feasibility of realizing total flux scales without using distribution photometry

Amplifier-Detectors. High gain amplifiers have been developed which allow for measurement of radiometric quantities over 13 decades. The amplifiers rely upon a careful choice of detectors with high shunt resistance and on considerable care in assembly. The devices can be absolutely calibrated and furnished with a variety of filters for use in photometry.

LBIR Radiometry Project (Datla, Ebner, Proctor)

A facility for radiance-temperature calibrations of cryogenically-cooled blackbodies has been developed, and is now used for routine calibrations. The system features a 60 cm diameter, 170 cm long vacuum chamber which can have its inner volume maintained at 20 K. An absolute cryogenic radiometer with sensitivities of 1 nW is used to measure the total power from a user supplied black body source. Given the geometry, a radiance temperature can be deduced with the appropriate corrections for diffraction. A program to develop a capability for spectral calibrations of low-temperature sources and cryogenically-cooled detectors is under development.

Calibrations. There have been three calibration this year of user supplied blackbody sources. The sources operate from 150 K to 450 K and have several different apertures. The total power under using different apertures and at various temperatures is measured and reported along with the dimensions, diffraction corrections, and error analysis.

QED Comparison. The cryogenic radiometer used on the LBIR facility was intercompared with a commercial absolute radiometer used as an absolute standard. The intercomparison, performed at 622 nm and a power lever of 100 microwatts, indicated agreement by the two absolute devices to better than 0.5%. Additional testing and evaluation to establish and certify the measurement base is underway.

Superconducting Bolometer. The further development of the NIST LBIR facility will require a capability to measure radiant-power levels in the 0.1 nW range. To achieve this goal, the NIST Boulder and Gaithersburg laboratories are collaborating in the development of a prototype radiometer using the principle of a kinetic-inductance bolometer operating at cryogenic temperatures.

Planning. At the request of sponsoring agencies, a long range research and development plan was produced which gives direction in calibration related research and development. Input from the sponsors and the industrial users of the service was solicited and incorporated into the final document. Engineering plans for developing infrared calibration sources and for obtaining spectral capability in the facility have been started.

Facilities Development Project (Fowler, Tobin)

The staff in this project furnish support for the Division in electronic and mechanical design and in maintenance of the research and calibration facilities. Additional efforts involve design development for sophisticated radiometric purposes in other agencies. This includes design of wide aperture blackbody sources and work to establish a new calibration protocol for the aviator night vision goggles used by DOD.

Advanced Radiometry Project (Migdall, Parr)

New concepts in optical radiation measurement are developed by applying technical capabilities from other areas of science and technology. This includes applications of atomic physics, RF measurement technology, laser physics and synchrotron radiation.

Optical Heterodyne Densitometry. A laser heterodyne detection method has been developed to measure optical transmission densities over 12 orders of magnitude with a Mach-Zehnder interferometer. The technique employs frequency modulation in one arm of the interferometer and allows the transmittance of filters to be compared to RF electrical attenuation standards. The method has been used at 633 nm and 10.6 m, and the feasibility of spectral measurements with tunable lasers has been demonstrated. A cryogenic dewar to enable the study of transmission of materials at low temperature has been designed and procured.

Angle-Resolved Photoelectron Spectroscopy (ARPES). These studies use the tunable, narrow-band uv radiation from synchrotron sources (SURF-II and SRS at Daresbury, U.K.) along with high-resolution spectrometers to measure photoemission processes.

Planning. The staff has developed proposals for providing high optical density materials as SRM's and for application of highly excited atoms as IR and microwave detectors.

II. Spectrophotometry Group (J. J. Hsia, Leader)

The Spectrophotometry Group is responsible for the establishment and dissemination of primary measurement scales from UV to IR for transmission and reflection spectrophotometry, densitometry, and bidirectional scattering metrology, and for the development of methods for the radiometric characterization of optical components and materials.

UV-VIS-NIR Spectrometry Project (Eckerle, Barnes, Fink, Hsia)

The objectives of this project are to maintain and upgrade state-of-the art reference instruments, conduct international intercomparisons, develop SRMs, develop intrinsic standards with critical data, support secondary laboratories and perform measurement services.

Regular Transmittance. NIST served as the central laboratory in an international intercomparison of glass filter transmittance measurements in the 0.92 to 0.001 range. The agreement among the four participants (Hungary, F.R.G, U.K., U.S.A.) varied from 5×10^{-4} to 8×10^{-6} transmittance units. A second phase of the intercomparison is under way, involving Canada, France, and the U.S.S.R. as additional participants.

Instrument Upgrade. The hardware and software of the automation system for the research high accuracy transmittance spectrophotometer have been upgraded. The motor system and its software for the reference reflectance spectrophotometer have been upgraded. The design of a high accuracy integrating sphere has been completed. This sphere is for an ultraviolet-visible-near-infrared spectrophotometer which will be used at NIST as a transfer instrument for diffuse reflectance calibration.

Liquid V(λ) Compensating Filters. The V(λ) function is the CIE spectral luminous efficiency function for photopic vision. Liquid V(λ) compensating filters have the potential for use in detector based photometry. They could provide a versatile and inexpensive way of compensating the spectral response of silicon photodiodes. A study of the suitability of such filters for this purpose has been undertaken. An attempt was made to duplicate the results given in a preprint of a USSR paper. Their results are based on a two-component solution for matching the V(λ) curve using a silicon photodiode. Using a revised formulation the deviation from V(λ) was $f_1' = 8\%$. The chemicals used for two-component solutions are $CuC1_2\bullet2H_2O$ and $K_2Cr_2O_7$. Also, a four-component solution is used for thermopile detectors. For a four-component solution, two additional chemicals are used - $(NH_4)_2SO_4$ and $CoSO_4\bullet7H_2O$, For a four-component solution, a deviation, f_1', from the V(λ) curve was approximately 5%. Studies were performed to determine the effect of stabilizing the solution by using 0.001N perchloric acid ($HC1O_4$). The additions of 0.001N acid to the solution has no appreciable effect on the transmittance. Aged chemicals have the same transmittance in solution as fresh chemicals. A temperature controlled sample holder has been constructed to begin measurements of molar absorptivity of domestic chemicals.

45°/0° Reflectance Factor. A laboratory intercomparison is being organized to test the methods of preparation and uniformity of the 45°/0° reflectance factor of pressed PTFE powder. A previous intercomparison of 6°/hemispherical reflectance factors demonstrated interlaboratory agreement of 0.25% in the 350 to 1100 nm range.

Standard Reference Materials (SRM's). NIST provides a large number of SRM's for the following spectrophotometric parameters: regular spectral transmittance, transmission optical density, spectral absorbance, wavelength, regular spectral reflectance, directional/hemispherical reflectance.

Measurement Services. In FY90 calibration services for industrial laboratories totaling $22K were performed. Special calibration services for spectral transmittance, specular reflectance, diffuse reflectance and 45°/0° reflectance factor have been provided. Calibrations were performed for six glass V(λ) filters to be used in detector based photometry. Twenty support measurements have been provided for NIST staff. Calibrations have been provided to NASA for 6°/hemispherical reflectance measurements.

Reference Densitometer. The NIST reference densitometer has been converted to the ISO 5/2 geometry and calibrations are now made on an opal-glass instead of integrating-sphere scale.

Transmission and Reflection Densitometry. Optical densitometry has applications in many industries, e.g. study of the quality of welds and other non-destructive evaluations. 150 x-ray step tablets (SRM 1001) and 150 photographic step tablets (SRM 1008) have been certified for use in the calibration of transmission densitometers in the transmission density range 0 to 4. Several special tests have been performed on step tablets, film, and filters for transmission density or absolute visual reflection density for industrial laboratories.

IR Spectrometry Project (Hanssen, Eckerle, Asmail, Hsia)

The plan of this project is to develop IR reference instruments, establish measurement capabilities, develop new methodology, apply new technologies, conduct research in diffusers and perform measurement services.

IR Regular Transmittance. The development and testing of a collimated-beam attachment have been completed for an IR spectrophotometer for use in measuring the transmittance of materials from 2 to 22 μm.

IR Specular Reflectance. An alignment device to improve the accuracy of specular reflectance measurements with commercial instruments has been developed. It allowed measurement of a gold mirror with an uncertainty less than 0.0025 between 2 and 22 μm.

IR Reflectance Survey. A questionnaire on IR diffuser requirements was sent out to the surface scattering community. The most salient remarks received include requirements of total hemispherical reflectance, durability, uniformity over surface and an overall sense of immediate need.

ZnSe Diffuser Reflectance. The diffuse and directional reflectance in the infrared of several samples of pressed ZnSe powder, a candidate infrared diffuser, has been measured in collaboration with the Naval Research Laboratory. It was found that high pressure compacted ZnSe powder exhibited both lower values of reflectance throughout the 2 μm to 16 μm wavelength region of the measurement, and greater specularity than the low pressure compacted powder; the low pressure ZnSe compact exhibited reasonably diffuse scattering but only had a high reflectance (>90%) near 2 μm.

Diamond Film Diffuser. A study has been started to investigate the physical properties of materials required to produce high reflectance and/or near-perfect diffusing samples in the IR. These properties include those directly affecting light scattering such as the particle size, shape, packing density, and complex dielectric function, as well as those indirectly affecting the performance such as durability, resistance to incident radiation, various environments, including atmosphere and vacuum, mechanical vibration, etc. A new candidate material which has many attractive properties, including low absorbance beyond 7 μm is diamond. Diamond films and particles can be grown by chemical vapor deposition at NIST.

Analysis of Methods for Absolute Diffuse Reflectance Measurement. At present, in the visible spectral region there are several methods being used to make absolute measurements at various universities, industries, and national laboratories. Most make use of the integrating sphere, but vary in the use of measurement geometry, baffles and supplementary spheres. The accuracy in and applicability to the infrared region for each method will be examined, and will lead to the design and construction of an instrument at NIST for absolute measurement in the infrared from 2 μm to 16 μm.

IR Wavelength Standards for FTIR Spectrometry. Water and carbon dioxide absorption bands have been used to characterize the wavelength accuracy of a FTIR instrument. Studies of polystyrene absorption bands as ir wavelength standards are under way.

BSDF Metrology Project (Asmail, Hanssen, Hsia)

The goal of this project is to unify national BSDF measurements, through developing reference instruments, establishing measurement capability, developing measurement technique and developing SRMs.

Clean Room. For the BRDF measurement facility a Class-10 clean room has been constructed. There are still some problems however with the air flow balance between the three rooms: clean lab, gowning area and viewing area. It is believed that a leak persists behind the wall panels and the contractor is currently working towards locating and resolving this problem. Many delays due to lost shipments and poor plant scheduling have prolonged the completion date.

LBRS. All components have been received for the low background BRDF reference system (LBRS) with a N_2 purged ambient transmittance, fixed 45°/0° geometry. The alignment of the system is pending the completion of the clean room. Once the LBRS is aligned, the effect of ambient conditions and the imaged path length on the instrument signature noise floor will be studied.

MARS. The multiple-angle BSDF reference system (MARS) is in the process of being constructed. It will have a fixed source system with shared use of optical layout by various lasers and a rotating detector module. It will include full hemispherical coverage for both incident and viewing angles and will include laser wavelengths from the UV to the IR. Detector sensitivity limits for three wavelengths within the silicon (Si) detector range have been evaluated according to a desired 10^{-6} sr^{-1} sample with a 10^{-8} sr^{-1} instrument signature noise floor. A NIST developed 14 decade Si photodiode will be used above 325 nm. It has a 10^{-16} ampere current sensitivity at 1 mHz. The Si detector will be calibrated absolutely, is not subject to magnetic field fluctuations, and is highly stable. However, at 325 nm, a microchannel plate will replace the silicon photodiode.

Consultation. Our staff members have provided extensive consultation to the ASTM subcommittee E12.09 on scattering in regard to the technical content of the standard for angle-resolved surface scatter measurements. A draft of a standard test method for BRDF scattering measurements is in the process of committee balloting.

III. Thermal Radiometry Group (R. D. Saunders, Leader)

Basic research in blackbody physics, optical radiation sources and calibrations of radiometric sources are preformed by this group. The primary areas of activity is in radiation temperature, radiance and irradiance.

Radiation Temperature Project (Walker, Bruening, Hunter, Waters)

Basic research in radiation temperature measurements are carried out by the personnel of this project. In the past year, the main goal of this project was to convert to the ITS-90 temperature scale and to set up the NIST Radiation Temperature Scale.

Spectroradiometric Determination of the Freezing Temperature of Gold. An absolute measurement of the temperature of freezing gold was performed by measuring the spectral radiances of a gold blackbody relative to those of a laser-irradiated integrating sphere which was calibrated with absolute silicon detectors and an electrically calibrated radiometer. The result obtained (1337.33 K) agrees exactly with the gold-point assignment in the International Temperature Scale of 1990 (ITS-90).

New NIST Scales of Thermal Radiometry. Following the absolute determination of the freezing temperature of gold, the Division has adopted new measurement scales for its measurement services in radiation thermometry, spectral radiance and irradiance, and photometry. These scales became effective on July 1, 1990, and supersede the previous IPTS-68 based scales. The changes in reported calibration values are within quoted uncertainties and have resulted in small improvements in accuracy and better consistency with other radiometric scales.

Intercomparison of the NIST Radiation and Contact Thermometry Scales. The consistency of these scales in the silver/gold-point region has been verified by spectroradiometric and high precision thermocouple measurements on a variable-temperature heat-pipe blackbody. The introduction of the ITS-90 has removed small deficiencies of the contact thermometry scale, and the two scales now agree within quoted uncertainties. In the past the Material Processing Metrology Division has maintained the temperature scale up to the freezing temperature of gold and the Radiometric Physics Division has maintained the scale at the freezing temperature of gold and above. However with the acceptance of the ITS-90 Temperature Scale, the radiation temperature scale starts at the freezing temperature of silver. The temperature of the first cavity was measured by matching it to the radiance of either the freezing gold or silver blackbody. The second cavity temperature was measured by thermocouples that embody the ITS-90 Temperature Scale below the freezing gold temperature.

Spectral Radiance Ratio of Freezing Silver and Gold. A preliminary spectroradiometric measurement of the silver/gold radiance ratio resulted in a temperature of 1234.95 K for freezing silver which agrees within 0.02 K with the ITS-90 freezing silver-point assignment. The freezing temperature of silver is determined by using Planck's Law and the radiance ratio of the two freezing point blackbodies. At this time we have a 40mK discrepancy depending on what type of detector (silicon or photomultiplier) is used. Although the difference is well within our uncertainty, we observe a statistically significant difference between the two detectors.

Gold and Zinc Blackbodies. Newark Air Force Base is the primary calibration laboratory for the Air Force. The blackbodies that NBS delivered 20 years ago have deteriorated from use. Therefore a project has been established to build and characterize a new set of blackbodies that are interchangeable with NIST. The materials for these blackbodies have been ordered. The crucibles have been designed and built. The crucibles will be filled in the next few months and the characterization will start.

Thermal Imaging Laboratory. NIST has developed facilities for optical temperature measurements in the 2 to 15 μm region. Two water-bath blackbodies have been developed as a primary standard for calibrating thermal imaging devices between 0 and 100°C. A PtSi camera has been installed for measurements of temperature gradients. These two large area water-bath blackbodies have been developed in cooperation with a Navy sponsored CCG project. One of the blackbodies belongs to the Navy and the other blackbody stays at NIST for its thermal imaging program. These blackbodies will serve as a base for calibrating low temperature blackbodies and thermal imagers such as the Forward Looking Infrared Radiometer (FLIR). The water-bath Blackbody for the Navy has been characterized and delivered to the NAVY at Corona, California. The primary blackbody that will reside at NIST is in the process of being characterized and calibrated. A PtSi camera has been installed for measurements of temperature gradients. The facility has the capability to characterize and calibrate blackbodies in the temperature region 0-100°C and in the spectral range 3-14μm.

As part of the Thermal Imaging Program, different types of scanning radiometers are being investigated as possible replacements for the Barnes' type radiometer. The first choice because of its desirable properties was the PtSi camera. Also it was felt that this camera would be a good choice to scan silicon targets used to characterize thermal imagers. The PtSi camera has finally arrived and has been put into use. Although the camera has not been fully characterized, it has been very useful in measuring the temperature gradients of the water bath blackbodies. It is also being used to measure the temperature profile of salt detectors that are under study to determine their operating characteristics as a function of temperature. The camera has been interfaced into a PC computer, and software to handle the data reduction has been started. The main limitation of the camera is its 8-bit frame grabber. Therefore, a 12-bit frame grabber is being installed. Initial test of the camera indicates that the camera has Minimal Resolvable Temperature (MRT) of less than 50mK.

Biological and Low Level Radiometry Project (Thompson, Bruening, Walker)

Basic research leading to the development of low level radiometric standards is the main function of this group.

Luminescence SRM's. NIST supplies, or has under development, a number of luminescent standards for use in clinical chemistry and medical research. A low-level spectrofluorimeter is under development for the characterization of quantum yield standards. The first of these luminescence SRM's are the glass fluorescent SRM's. In the past year, a group of SRM standards has been calibrated. In FY-91 a detailed report of this work will be published. Dr. Thompson received a special award from the Office of Standard Reference Materials for this work.

A second set of these SRM's is the Chemiluminescence SRM's. NIST is investigating the feasibility of using chemiluminescence as SRM fluorescent standards. This task required that a new laboratory be set up and new chemical processes be developed. The laboratory is completed and the equipment to make the measurements is being set up. The testing of these new SRM's will start next FY.

Low-Level, Large-Area Radiance Sources. To provide stable, large-area spectral radiance standards, quartz-halogen lamps of varying wattage have been combined with integrating spheres. The spheres are equipped with silicon detectors for setting output levels. These sources have been used for calibrations of space-borne imaging radiometers and tests of aviators' goggles under starlight conditions The measurement on their stability has been completed and the data is now being analyzed. The high level spectral radiance calibrations are now in progress. The measurement setup has to be reconfigured because the scattered radiation from the sources and surroundings are too high. A prototype is being built and will be tested in the next few weeks.

Spectroradiometer to Measure Low Spectral Radiance Levels. A large throughput spectroradiometer is needed to measure the spectral radiance of low level fluorescent standards. A single UV grating monochromator with a prism pre-disperser was purchased for this work. This work has been put on hold until the new laboratory is in operation.

Support for Terrestrial Solar Irradiance Measurements. A capability to characterize spectrometers used to measure the terrestrial solar irradiance in the UV-B region is under development. These efforts are vital to national and international programs on climate changes, environmental pollution, and crop production. A reference spectroradiometer will be used as the primary standard for the USDA's terrestrial solar monitoring network. The instrument is now being built and will be delivered next calendar year. This task was funded in two stages with the procurement of the spectroradiometer being the first. In the second stage, if money becomes available in FY91, the instrument will be calibrated and characterized at NIST. After the instrument is characterized and calibrated, it will be used as the standard for the calibration of spectroradiometers used for the spectral region 200-400nm. An intercomparison of UV-B instruments was held at the EPA Raleigh site in November. There were 8 different instruments participating in the intercomparison with the NIST instrument the primary spectroradiometer. These results are being written up to be published early next year.

Measurement Calibration Project (Saunders, Jackson, Gibson, Hunter, Waters)

Calibrations for radiation temperature, spectral radiance and spectral irradiance are the main tasks of this project.

FASCAL Accurate Detector (FAD). A high accuracy photometric corrected silicon detector was installed on FASCAL to monitor the stability of the measurement process. This detector package provided an independent check of the spectral irradiance scale in the visible spectral region with the idea of extending this technology into the UV and Infrared. A second benefit of FAD is comparison of the photometric value measured by the detector to that of the calculated photometric value from the measured spectral irradiance of FASCAL. A set of data has been taken and the agreement between the photometric and the spectral scales was on the order of 0.5%. This was not too disappointing since the distance measurement (50cm) is very critical to these determinations.

CCPR Spectral Irradiance Intercomparison. NIST served as the central laboratory in an intercomparison of the spectral- irradiance scales of 13 national laboratories. This work was set up by the CCPR of the BIPM with NIST as the coordinating laboratory. The measurements at NIST have been completed and the comparison of the data from the other laboratories is close to being finished. The participants have returned their data and an initial analysis has been preformed on the data. The initial results show that the national laboratories agree to $\pm 10\%$ in the UV and infrared and about $\pm 1\%$ in the visible. Preliminary results were submitted to the CCPR in September, 1990. A committee has been established to determine the final form of the results and presentation of the data. Mr. Walker of NIST is the chairperson of this committee. The final paper on the intercomparison will be completed by May 1991.

Solar UV Intercomparison. NASA and the solar community needed a method to ensure that all radiometer systems measuring the UV solar irradiance were on the same base and measuring the same radiometric quantities. NIST developed an instrument package, consisting of four tungsten-halogen lamps, four deuterium lamps, mounting hardware and power supplies, for an intercomparison of uv spectral irradiance measurements by five U.S. and European members of the solar-monitoring community. This calibration package is a turn-key system. Also, it comes with a complete set of instruction on how to make the measurements. The first round of the intercomparison has been completed and a workshop to discuss the results has been completed. The first round went very smoothly and the intercomparison uncovered calibration errors of $\pm 5\%$ and larger, as well as interpolation errors of 10 - 20%. These errors could cause major measurement problems that would have made the space measurements invalid. The intercomparison calibration package has been calibrated twice and is scheduled for a recalibration in December, 1990.

NIST/VNIIOFI Intercomparison. NIST and VNIIOFI (U.S.S.R.) have conducted a bilateral spectral radiance intercomparison of tungsten ribbon lamps in the spectral range from 250 nm to 2400 nm. The largest differences observed were on the order of $\pm 1.5\%$. The USSR is the only other country in the world that derives spectral radiance from a blackbody source. This work has been completed and a paper is now being written for the NIST Journal of Research.

Calibrations. Calibrations done by this group are spectral irradiance, spectral radiance, and radiation temperature. There were about $30K of spectral irradiance calibrations, and $30K of radiation temperature calibrations carried out.

Pyrometry Upgrade. In the past year, the Pyrometry Facility measurement system was upgraded such that calibrations are turned around in several months instead of a year or so. The mechanical automation of the Pyrometry Facility has been completed and the software development is expected

to be completed by June 1990. The mechanical automation has decreased the turn-around time of pyrometry calibrations from a year to several months.

Heat-Gage Calibration Facility. The Center for Fire Research has been assigned the task to measure flammability of materials and calibration of secondary standards for the FAA. This project requires an accurate absolute detector calibrated against a blackbody source operating at a temperature of approximately 1300°C. Measurement of the linearity of the reference cavity radiometer has been completed using an argon laser with line powers up to 4 watts. The secondary transfer standards have been mapped for uniformity. This mapping shows that the response uniformity is very poor and that they must be used with a uniform radiator. This non-uniformity makes the calibration a little harder since a uniform source must be built. The reflectance of the black coating has been measured and will be used to calculate the correction needed at a particular blackbody temperature since the reflectance changes as a function of temperature. These detectors are now being characterized and calibrated using a blackbody operating in the temperature range 1000-1800°C.

Extension of Radiation Temperature Calibrations to the Near IR. A new state-of-the-art optical pyrometer is under development. It will allow temperature measurements to be performed at wavelengths throughout the visible and ir, and will help solve present problems with industrial temperature measurements. The new pyrometer will cover the spectral range 400nm to 1500 nm. The pyrometer has been designed and the components are presently being assembled. The characterization of the instrument will start in November 1990. It is expected that we will be able to start a calibration service in the first quarter of the calendar year.

Special Calibrations.

A radiation temperature lamp was calibrated at four wavelengths and two temperatures. This standard will be used to calibrate a two color pyrometer by Northwestern University.

The spectral radiance of a four foot sphere used by NASA for the calibrations of EOS type satellites was measured. Initial work was performed at NASA Goddard in September to resolve some long standing problems with non-NIST calibrations. This work will allow NASA to lower their uncertainty from 8% to approximately 1%. NASA has cited this work at the Absolute Radiometry Conference in Davos in September as a major contribution to the EOS project. This work is an ongoing project that will go on into next year.

NIST has performed one-time calibrations of the geometrically-total, spectral radiant flux of tungsten-halogen and high-pressure sodium lamps. These will be used as secondary photometric standards by members of the U.S. Lamp Testing Engineers' Conference.

INVITED TALKS

Division 534, Radiometric Physics

Cromer, C. L., "Intercomparison of Two Similar Cryogenic Radiometers," International Pyroheliometer Comparisons, Davos, Switzerland, September 20, 1990.

Datla, R., "Blackbody Calibrations at NIST LBIR Facility," Third Scene Generation Workshop, Arnold AFB, TN, July 10, 1990.

Datla, R., "Low Background Infrared Calibration Facility at NIST," Cryogenic Infrared Radiometric Sensor Evaluation Symposium, October 11, 1990, Space Dynamics Laboratory, Logan, Utah.

Eckerle, K. L., "Procedures, Data Analysis, and Results of an International Intercomparison of State-of-the-Art Regular Transmittance Measurements, Council for Optical Radiation Measurements (CORM), Rochester, NY, May 1990.

Eppeldauer, G., "Application and Characterization of Silicon Photodiodes for Radiometric and Photometric Standardization," CORM, Rochester, NY, May 9, 1990.

Hanssen, L., "Integrating Sphere Designs for Accurate Reflectance Measurements," 5th International Conference on Diffuse Reflectance, Chambersburg, PA, August 1990.

Houston, J., "The NIST High-Accuracy Cryogenic Radiometer," CORM, Rochester, NY, May 9, 1990.

Midgall, A., "Measuring Filter Transmittance Using Hetrodyne Detection," International Pyroheliometer Comparisons, Davos, Switzerland, September 21, 1990.

Saunders, R. D., "Pyrometry at NIST," Temperature Measurement Workshop, February 20, 1990.

Walker, J. H., "International Intercomparison of Spectral Irradiance," 1990 CORM Annual Conference, May 9, 1990.

PUBLICATIONS

Division 534, Radiometric Physics

Asmail, C., "Cleanliness Requirements for the Air in a BRDF Facility," Proc. SPIE 1165, (1989).

Barnes, P. Y., Hsia, J. J., "45°/o° Bidirectional Reflectance Distribution Function Standard Development," Proc. of SPIE 1165, (1989).

Ebner, S. C., Parr, A. C., and Hoyt, C. C., "Update On The Low Background IR Calibrtion Facility At The National Institute of Standards and Technology (Formerly NBS), SPIE 1110, 49 (1989).

Eckerle, K. L., Sutter, E., Freeman, G. H. C., Andor, G., and Fillinger, L., International Intercomparison for Transmittance, Metrologia 27, pg. 33-38 (1990).

Hanssen, L. M., "Effects of Restricting the Detector Field of View When Using Integrating Spheres," Appl. Opt, 28 (10) 2097 (1989).

Hardis, J. E., Peifer, W. R., Cromer, C. L., Migdall, A. L., and Parr, A. C., Using "Resonant" Charge Exchange to Detect Traces of Noble Gas Atoms, Inst. Phys. Conf. ser. No. 94; Section 5, 237 (1989).

Mielenz, K. D., Saunders, R. D., Shumaker, J. B., "Spectroradiometric Determination of the Freezing Temperature of Gold," J. Research NIST 95, 49 (1990).

Mielenz, K. D. and Hsia, J. J., "Effects of the International Temperature Scale of 1990 (ITS-90) on CIE Documentary Standards for Radiometry, Photometry, and Colorimetry, J. Res. (USA) NIST (Sept./Oct. 1990).

Migdall, A. L., Roop. B., Zheng, Y. C., Hardis, J. E., and Gu, Jun xia, "A Study of the Use of Heterodyne Detection to Measure Optical Transmittance Over A Wide Range," Appl. Opt. (1990).

Thompson, A., and Eckerle, K. L., "Fluorescent Emission Standards for the Calibration of the Relative Response of Spectrofluorimeters in the Visible Region," NIST Certificate Standard Reference Material 1931 (1989).

Thompson, A., Eckerle, K. L., "Standards for Corrected Fluorescence Spectra," SPIE Proceedings, Fluorescence Detection III, 1054, 20 (1989).

Snail, K. A., and Hanssen, L. M., "Integrating Sphere Designs with Isotropic Throughput," Appl. Opt. 28 (10) 1793 (1989).

Wang, T. M., Eckerle, K. L., and Hsia, J. J. "Absolute Specular Reflectometer with an Autocollimator Telescope and Auxiliary Mirrors," NIST TN 1280 (1990).

West, J. B., Hayes, M. A., Parr, A. C., Hardis, J. E., Southworth, S. H., Ferrett, T. A., Dehmer. J. L., Hu, X-M, and Marr, G. V., "A High Resolution Angle Resolved Photoelectron Spectroscopy Study of N_2," Phys. Scripta 41, 487 (1990).

PUBLICATIONS IN PREPARATION

Division 534, Radiometric Physics

Asmail, C., "Bidirectional Scattering Distribution Function (BSDF): A Systematized Bibliography", (to be published NIST J. Res. Jan-Feb (1991)).

Bruening, Robert, "Instructions for Operating NIST Water Bath Blackbodies," (to be published as an NISTIR)

Cromer. C. L., "A New Spectral Response Calibration Method Using A Silicon Photodiode Trap Detector," (Proc. of the Measurement Science Conference, 1991)

Datla, R. U., Roberts, J. R., and Bhatia, A. K., "Relative Populations of Excited Levels within the Ground Configuration of Si-like CU, Zn, Ge and Se Ions," (to be published in Phys. Rev. A)

Eppeldauer, G. and Hardis, J. E., "Fourteen Decade Photocurrent Measurements with Large Area Silicon Photodiodes at Room Temperature," (to be published in Appl. Opt.)

Hanssen, L. M., Snail, K. A., and Morrish, A. A., "New Instrumentation for Measuring Emittance", HAVE Forum 88, LO Symposium, Atlanta, GA, March 1988 (Proceedings in Press).

Mielenz, K. D., Saunders, R. D., Parr, A. C., and Hsia, J. J., "The 1990 NIST Scales of Thermal Radiometry," (to be published NIST J. Res. Nov/Dec 1990)

Migdall, A. L., Roop, B., Zhen, Y. C., and Gu, J., "A Study of the Use of Heterodyne Detection to Measure Optical Transmittance Over a Wide Range," (to be published in Appl. Opt.)

Migdall, A. L. and Roop, B., "Measuring Filter Transmittance Using Heterodyne Detection," (to be published in Metrologia)

Roy. P., Bartlett, R. J., Ferrett, T. A., Parr, A. C., Southworth, S. H., and Hardis, J. E., "Vibronic Coupling and Other Many-Body Effects in the $4\sigma g^{-1}$ Photoionization Channel of CO_2" (to be published in J. Phy.)

Thomas, D. B. and Zalewski, E. F., "Precision Coherent Radiation Measurements Using State-of-the-Art Silicon Photodiodes," (to be published in J. Res. Natl. Inst. Stands. Tech.)

Thompson, A. and Eckerle, K. L., Standards for Corrected Fluorescence Spectra (to be published in SPIE Proceedings).

Walker, J. H., "The Faint Object Spectrograph Calibration," (in preparation).

Division 534, Publications in Preparation (cont'd)

Walker, J. H., "Intercomparing the Optical and Resistive Temperature Scales," (in preparation).

Zhu, Q. and Walker, J. H., "A Precise Determination of the Phase Equilibrium Temperature of Sodium Chloride" (in preparation)

Zhu, Q. and Walker, J. H., "Design and Preparation of a Sodium Chloride Blackbody and Its Usefulness," (in preparation).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 534, Radiometric Physics

Clara Asmail

Member, ASTM E-12.09, Scattering

Yvonne Barnes

Member, ASTM E-12 Committee, Appearance of Materials

Kenneth L. Eckerle

Member, ASTM E-13 Committee on Molecular Spectroscopy, Subcommittee E-13.01 on Ultraviolet and Visible Spectroscopy, Subcommittee E-13.03 on Infrared Spectroscopy, Subcommittee E-13.06 on Luminescence.

Member, CIE TC2-28 on Methods of Characterizing Spectrophotometers.

Laurance E. Fink

NIST Representative, ANSI IT2 on Photographic Sensitometry and IT2.28 on Densitometry

Jonathan E. Hardis

Member, U.S. National Committee of the CIE.

Jack J. Hsia

Secretary, CIE Division 2, Physical Measurement of Light and Radiation.

Chairman, CIE TC 2-11 Technical Committee on Goniophotometry.

Secretary, U.S. National Committee of the CIE.

Member, ASTM E-12 Committee, Appearance of Materials (Spectrophotometry, Colorimetry, Geometric Properties, and Scattering).

Member, ASTM E-13 Committee, Molecular Spectroscopy; Subcommittee E-13.01, Ultraviolet and Visible Spectroscopy; E-13.03, Infrared Spectroscopy, and E-13.06, Molecular Luminescence.

Division 534, Technical and Professional Committee Participation and Leadership (cont'd)

Klaus D. Mielenz

Vice President, U.S. National Committee of the CIE.

Director, CIE Division 2, Physical Measurement of Light and Radiation.

Member, ASTM E-13 Committee, Molecular Spectroscopy; Subcommittee E-13.06, Molecular Luminescence.

Member, IES Subcommittee CO12, Nomenclature.

Ex officio member, CORM Board of Directors

Member, OSA International Affairs Committee.

Member, Advisory Board, Munsell Color Science Laboratory, Rochester Institute of Technology.

Albert Parr

Visiting Senior Fellowship, Aberdeen University, Scotland.

Member, Queen Match Calibration Review for SDC.

Robert D. Saunders, Jr.

Member, ANSI Z311, Photobiological Safety of Lamps and Lighting Systems.

Member, IES Photobiology Committee.

Member, CIE TC2-05, Definition and Measurement of Distribution Temperature.

Alternate, ASTM E-20, Temperature Measurements

Alternate, ASTM E-44, Solar Energy Conversion

Douglas B. Thomas

Member, U.S. National Committee of the CIE

Alternate, ASTM E-20 Temperature Measurements

Member, ASTM E44, Solar Energy Conversion.

Member, U.S. National Committee of the CIE.

Division 534, Technical and Professional Committee Participation and Leadership (cont'd)

William R. Waters

Member, ASTM Subcommittee E20.20 Radiation Thermometry.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 534, Radiometric Physics

C. Asmail provided consultation to Oak Ridge National Laboratory of DoE on diagnostic and low level BRDF standards for large mirror evaluation.

P. Y. Barnes and C. Asmail provided consultation to NASA on measurements and calibrations of diffuse reflectance and BRDF for ozone monitoring instruments.

G. Eppeldauer and J. Hardis provided consultation to Newark Air Force Base of DoD on high sensitivity photometric and radiometric measurements.

G. Eppeldauer and J. Hardis provided consultation to Phil Wychorski of Eastman Kodak Company on high sensitivity photometric and radiometric measurements.

L. M. Hanssen provided consultation to John F. Gerhard of Rockwell International on integrating sphere design for reflectance measurements.

J. J. Hsia provided consultation to Robot Systems Division, NIST on measurements of diffuse reflectance for robot vision research.

STANDARD REFERENCE MATERIALS

Division 534, Radiometric Physics

1. SRM 1001, X-Ray Film Step Tablet

   For calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for transmission densities from 0 to 4.

2. SRM 1008, Photographic Step Tablets

   For calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for transmission densities from 0 to 4.

3. SRM 1010a, Microscopy Resolution Tests Charts

   For determining the resolving power of microscopy systems.

4. SRM 2061, Reflection Step Tablets

   For calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for reflection densities from 0 to 2.

5. SRM 2019 and 2020, White Ceramic Tile for directional-Hemispherical Reflectance from 350 to 2500 nm. SRM 2021 and 2022, Black Porcelain Enamel for directional-Hemispherical Reflectance from 280 to 2500 nm. SRM 2015 and 2016, White Opal Glass for directional-Hemispherical Reflectance form 400 to 750 nm.

   For use in calibrating the reflectance scale of an integrating sphere reflectometers.

6. SRM 2003b, First Surface Aluminum Mirror for Specular Reflectance form 250 to 2500nm. SRM 2011, First Surface Gold Mirror for Specular Reflectance form 600 to 2500 nm. SRM 2023, 2024, and 2025 Second Surface Aluminum Mirror for Specular Reflectance form 250 to 2500 nm.

   For use in calibrating the photometric scale of specular reflectometers.

7. SRM 2009, 2010, 2013, 2014 Didymium-Oxide Glass, Wavelength Standards between 400 and 760 nm.

Division 534, Standards Reference Materials (con't)

8. SRM 2034 Holmium oxide in Perchloric Acid Solution as Wavelength Standards between 241 and 640 nm.

9. SRM 1920 Near Infrared Reflectance Wavelength Standards from 740-2000 nm.

10. SRM 1931 Fluorescence Emission Standards for the Visible Region.

CALIBRATION SERVICES PERFORMED

Division 534, Radiometric Physics

Type of Service	Customer	SP250	Number of tests
Pyrometry		35010C thru 35070S	12
	Defense & Aerospace		6
	Instrument & Cal labs		2
	Electrical & Materials		4
Spectroradiometry - Sources		39010C thru 39060S	15
	Defense & Aerospace		3
	Instrument & Cal labs		4
	Lighting & Photography		5
	Electrical & Materials		1
	Foreign		2
Spectroradiometry - Detectors		39070C thru 39080S	9
	Defense & Aerospace		3
	Instrument & Cal labs		4
	Lighting & Photograph		2
Photometry		37010C thru 37180S	21
	Defense & Aerospace		6
	Instrument & Cal labs		3
	Lighting & Photography		6
	Foreign		5
	Electrical & Materials		1
Spectrophotometry		38010C thru 38100S	22
	Defense & Aerospace		8
	Instrument & Cal labs		5
	Lighting & Photography		1
	Foreign		1
	Electrical & Materials		7

TEST AND EVALUATION REPORTS

Division 534, Radiometric Physics

1. Cryogenic Blackbody 200-450 K for Lockheed, January 1990
2. Cryogenic Blackbody 200-450 K for Arnold Engineering Development Center, April 1990.
3. Cryogenic Blackbody 20-450 K for Rockwell International, August 1990.

SPONSORED SEMINARS

Division 534, Radiometric Physics

Johnson, Frederick C., "PC'S and Work Stations at NIST," NIST, Gaithersburg, MD, November 1989.

Ohno, Yoshihior, "Silicon Photodiode Self-Calibration Using White Light for Photometric Standards," NIST, Gaithersburg, MD, October 1989.

TECHNICAL ACTIVITIES

Division 535, Radiation Source and Instrumentation

The division's principal activity this year was the development of two major radiation sources, the 185-MeV racetrack microtron (RTM) electron accelerator and the NIST Free-Electron Laser (FEL). The RTM was designed to have a set of beam characteristics that would be unsurpassed anywhere in the world: a continuous pulse train, low emittance (submillimeter spot size), less than 40 keV energy width, and usable average power up to 100 kW. (Electron storage rings can also have high average beam power, but only a small fraction can be extracted without losing the stored beam.) Measurements at 17 MeV have confirmed that the beam surpasses all design specifications; measurements at full energy were scheduled for mid-FY 91.

A major planned application of the RTM electron beam, with a modified injector, is to drive the FEL. Since 1987 we have been supported by the SDIO Medical FEL Program to construct the FEL as an intense source of photons, tunable in wavelength from 200 nm to 10 μm, for research in medicine, biology, chemistry, physics and technology. Like the RTM, the FEL beam would have unique properties to enable experiments not feasible with other light sources. Early this year CRR management convened a panel of accelerator and FEL experts from outside NIST to review the design, construction and management of the RTM/FEL project. The report of the panel, chaired by Dr. Philip Morton of SAIC, is included as an Appendix. In summary, the panel concluded that the design could be built to satisfy its requirements and that the staff was qualified but barely sufficient in number for the project.

A great deal of progress was made this year on the final stage of RTM construction: installation of the beam lines to recirculate the beam through the accelerating structure (linac). A new power converter for the RTM klystron was ordered, and a new RTM control system was installed that can be easily expanded to control both the FEL and user experiments. A beam line was designed for commissioning the RTM, and all the major magnets for this line were either installed, on hand, or in construction. A high-peak-current electron gun was ordered for operation of the RTM as an FEL driver. The vendor completed construction of the FEL undulator with a field quality surpassing specifications, and a system for aligning the FEL end mirrors was selected and ordered. Physical modifications to the FEL area were completed.

In September, 1990, with RTM commissioning scheduled to start in six months, we were informed that SDIO was unable to continue to support construction of the FEL after 1990. With the prospect of continuing the RTM development with a sub-critical staff, shortly afterwards the NIST

Director announced his decision to terminate the RTM project. Since then the Division's effort has been restricted to bringing ongoing tasks to completion in a manner consistent with the possible use of the equipment by other organizations. In the following sections we detail activity on the RTM/FEL and the Division's other projects.

I. Racetrack Microtron (M. Wilson)

This 185-MeV, 500-μA electron accelerator, shown in Figure 1, consists of a 5-MeV injector feeding a racetrack microtron. In the microtron, a pair of 180° end magnets will recirculate the continuous electron beam through an 8-m, 12-MeV rf linac up to 15 times for an energy gain of up to 180 MeV. Up to 450 kW of microwave power from a single, continuous-wave (cw) klystron operating at 2380 MHz establishes standing-wave accelerating fields in both the injector (5-MeV) linac and the RTM (12-MeV) linac. The beam can be extracted from any of 14 separate return lines in 12-MeV steps.

This year procurement of all components for the return lines was completed, and installation is well along. An electron beam transport line for full RTM commissioning has been designed, and most of the magnetic transport components are on hand or in procurement. High-current beam transport for the new injector for driving the FEL at a peak current of up to 4 A has been calculated from the 120-keV electron gun to the exit of the 5-MeV linac. The high-current electron gun system was ordered. A decision was made to upgrade the RTM control system for improved reliability and expandability, to include control of the FEL. The resulting modifications to the control system are in progress.

a. RTM Construction (M. Wilson, R. Ayres, S. Bruce, R. Cutler, E. Lindstrom, A. Raptakes, and R. Vest)

In the past year a great deal of progress was made in completing the 14 return lines, the final stage in the construction of the RTM. All components of the return lines are now either installed or on hand. The 28 quadrupole electromagnets used for controlling the betatron tune of the recirculating beam have been assembled, tested, installed and aligned in the central section of the return lines. All 42 steering magnets have been assembled and field-mapped, and 14 of them were installed and aligned in the central section. The central section beam tubes were also installed. The extraction magnet (D11) was field-mapped and was installed on a support structure that allows it to be positioned on any return line by remote control. All return-line support structures are in place, and the remaining return-line devices are being installed: view screens, steerers, vacuum envelope and magnetic shielding. A modified version of the wire-scanners with an improved signal-to-noise ratio is undergoing tests prior to installation.

A beam transport line for commissioning the RTM was designed. Although the design requirements are simpler than those required to deliver the electron beam to the FEL, the commissioning line will provide accurate means of measuring the RTM beam emittance, energy, and energy spread. All of the magnetic elements have been designed and are on hand or in procurement. The first two dipole magnets, D12 and D13, have been assembled, field-mapped and mounted. D12 has also been aligned. The 2"-bore quadrupoles Q12 - Q21 are scheduled for delivery, fully tested by the vendor, in early 1991. The coils for the remaining dipole magnets (D14, D15 and D16) are

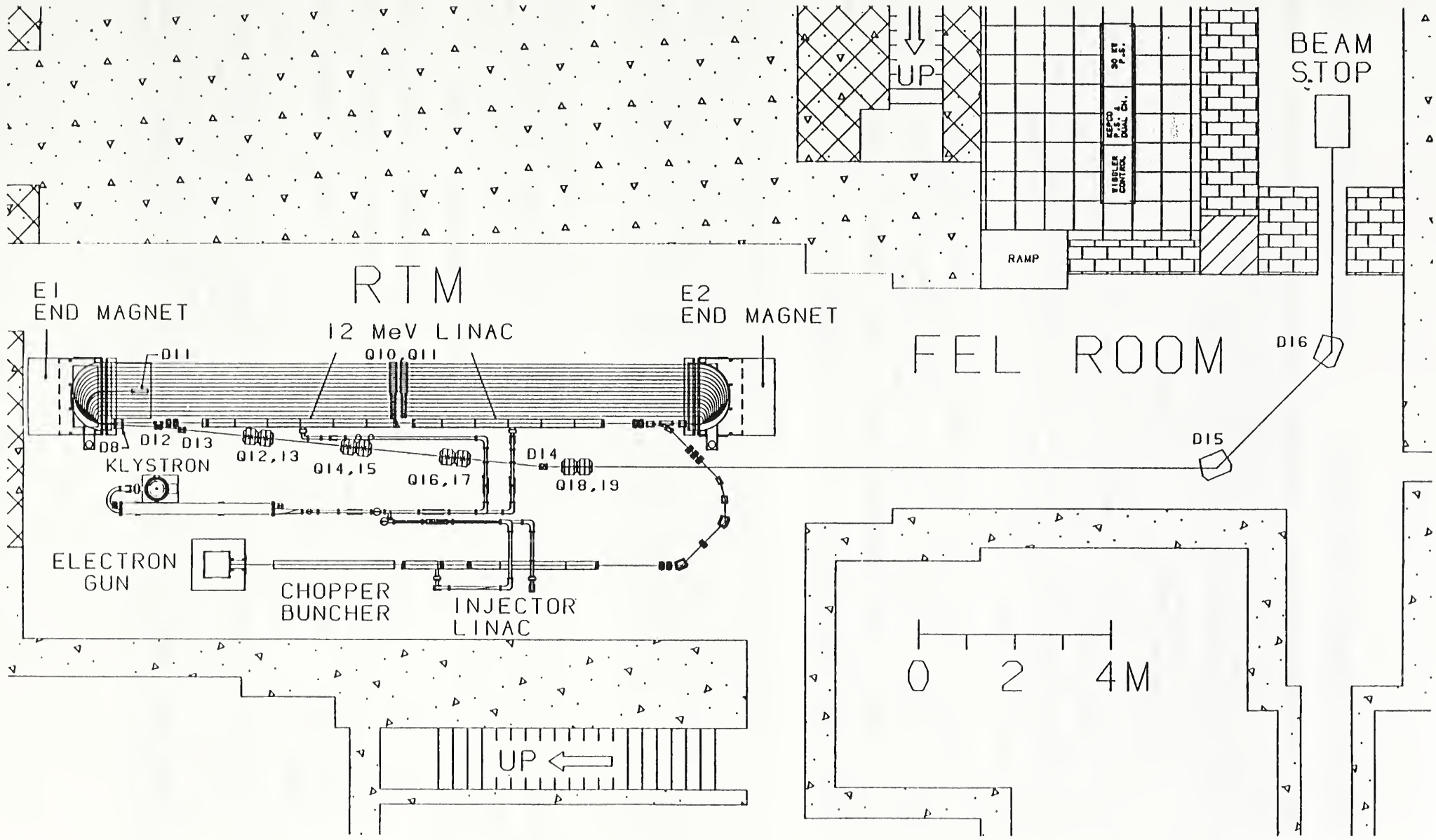

Figure 1. The NIST Racetrack Microtron (RTM) and the beam transport line designed to measure the properties of the electron beam of the RTM.

scheduled for delivery by the end of December, and the steel yoke and pole pieces for D14 were fabricated. The conceptual designs for the vacuum envelope and support structure for the commissioning line are complete, and the final design of individual components is underway. Construction of the 100-kW beam stop is nearly complete.

b. **High-Current RTM Injector** (Mark Wilson, E. Lindstrom, and R. Cutler)

The high-current injector for the RTM is designed to provide the 2-4 A, 3.5 ps electron beam pulses required by the FEL for lasing. This is 40 times the peak current of the present injector. The electron beam pulses will have repetition rates of 66.111 MHz and 16.528 MHz, which are subharmonics of the RTM microwave drive frequency of 2380 MHz and harmonics of the FEL cavity frequency of 16.528 MHz.

The high-current electron gun and pulsing system have been fully specified. On July 31, a contract was signed by a qualified vendor for delivery of the gun and pulser within one year. The results of computer modeling of the gun performance were received from the vendor, reviewed and accepted. Information from this modeling was then used to establish the design of a matching section for beam transport between the exit of the gun and the subharmonic chopper-buncher system. Eric Lindstrom has written a technical note on the matching section design.

c. **Beam Dynamics** (M. Wilson, E. Lindstrom and S. Penner (contractor))

Injection of high peak current at the 36th subharmonic of the RTM accelerator frequency results in fluctuations in the loading of the accelerating structure by the recirculating beam. We have calculated that, while these loading fluctuations may cause a phase "walk" of the recirculating beam, there is no effect on the phase stability of any selected extraction orbit, and therefore, no corresponding effect on the FEL performance.

The Beam Dynamics Group at the Continuous Electron Beam Accelerator Facility (CEBAF) has completed calculations of the effect of high peak current subharmonic operation of the RTM on the transverse beam breakup (BBU) instability. Their results support S. Penner's conclusion that the current threshold for subharmonic BBU in the RTM can, by tuning the return-line quadrupoles, be made higher than the planned maximum electron beam current for driving the FEL.

For commissioning the RTM, focus conditions have been established that prepare the beam envelope for accurate emittance measurements while simultaneously providing optimal beam size for high-resolution beam energy and energy-spread measurements at the exit of D15. This set of conditions will facilitate rapid, accurate measurements of the beam quality during RTM commissioning.

Electron beam transport beyond the beam stop has been calculated for electron energies between 5 MeV and 185 MeV. This transport line will deliver the RTM electron beam to a user area for high-energy radiation dosimetry and for studies of generating high-quality, short-wavelength radiation through such mechanisms as channeling, transition radiation from microstructures, and parametric x-radiation.

II. Free-Electron Laser (R. Johnson, C. Johnson, S. Penner (contractor), M. Price, and J. Rose)

A major application of the RTM electron accelerator is as a driver for a free-electron laser (FEL). The FEL, which was being constructed by NIST in collaboration with the Naval Research Laboratory (NRL), was planned to be the basis of a national user facility for fundamental and applied research with an intense, tunable photon beam. The radiation would consist of a continuous train of 3-ps pulses, tunable from 200 nm to 10 μm with transform-limited line width, and average power of 10 to 200 W. Excellent progress in both design and construction of the FEL has been made this year.

Construction of the undulator (wiggler) is essentially complete; delivery has been suspended until its disposition is determined. Although final deliveries of permanent magnets were delayed by well over a year, the contractor was able to compensate for a significant portion of that delay. The contractor has completed adjustments of the magnetic structure to insure compliance with the most difficult specification for the undulator, i.e., a RMS magnetic field error of less than 0.5%. Our analysis of magnetic field data supplied by the contractor has confirmed that they have indeed surpassed this specification. The ability to analyze undulator data locally was made possible by the excellent cooperation of Dr. Brian Kincaid (Lawrence Berkeley Laboratory) who supplied his extensive set of programs for this purpose. These programs were implemented here and allowed us to follow the progress in tuning the undulator.

Detailed calculations of factors which can affect FEL performance have continued at NRL. Over the last year they have considered the effects of phase jitter in the electron beam, the generation of coherent harmonics, and errors in the magnetic field of the undulator. Initial calculations which include phase jitter of the electron beam were performed using a semi-analytical formulation of the one-dimensional FEL oscillator in the linearized, small-signal, low-gain limit. The conclusion of this calculation is that the average gain is not affected significantly. Work will continue to extend these calculations to a full 3-D, nonlinear, self-consistent, oscillator code.

Errors in the magnetic field of the undulator can walk the electron beam off the undulator axis and out of the optical beam and can alter the phase between the electrons and the radiation. A code has been developed at NRL to predict these effects and their consequences on FEL gain. The code provides 3-D numerical simulations and includes multiple steering, transverse focussing, and correlations. Input to the model can be through generation of sets of random errors or actual measured errors. Calculations using sets of random errors within the specifications of the NIST undulator indicate that the gain of the FEL will not be severely reduced.

Potential designs for the optical alignment system were studied using a full-scale model of the cavity. From these studies a system using autocollimators was selected and specifications for the autocollimators set. The parts for this system were ordered. The use of the model cavity also led to specifications for a mirror mounting system, for which a preliminary engineering design was completed. This design features a method to hold up to seven mirrors in vacuum at each end of the cavity, which will allow rapid changes of mirrors.

Studies of thermally induced distortion of mirrors using a finite-element analysis (FEA) code have continued. In two cases where analytical solutions were possible, the FEA code produced acceptable

agreement. The final report from a Phase I Small Business Innovative Research grant to study mirror degradation due to harmonic radiation has been received. In the study an interesting annealing effect was discovered when the mirrors were subjected to broad-band UV radiation. This effect needs to be studied further as a possible method of preprocessing the mirrors for the FEL.

Preparations of the FEL area are complete. The air conditioning system in the FEL room and the FEL electronics room has been modified to improve cleanliness and reduce vibrations. The FEL electronics room was painted, a raised floor installed, lighting added, and electrical service for equipment racks was installed. Magnet power supplies, vacuum control equipment, and racks for other electronic equipment have been installed. Heat exchangers for the 100-kW beam dump and for magnet cooling have been installed in the FEL room. Radiation studies for the FEL equipment room and the FEL users room have been completed.

A paper on the NIST-NRL FEL[1] was selected for inclusion in "Current Overviews in Optical Science and Engineering I" in the SPIE Advent Technology Series.

III. Electronic Instrumentation (J. Whittaker, A. Marella, J. Owen, L. Shuman and N. Wilkin)

With the exception of the joint Fuze project with the Harry Diamond Laboratories, the Electronics Instrumentation Group has been almost solely occupied with assisting in the construction of the RTM during the past year. Initially the Group was responsible for procuring all the computers, CAMAC equipment and other components for the new RTM control system. This task was completed ahead of schedule. The Group stripped and rebuilt the control room for the accelerator and installed the computers, fiber optic cable links and CAMAC systems. Wiring of the control system is proceeding, with the removal of the old control system, which has now been completely replaced with the new system, and now additions to the control system are being installed. It was necessary to rebuild the quad phase shifters in the low-power rf system in order to meet CAMAC standards and improve their reliability. This proved to be time consuming, and part of the system has been checked successfully and the remainder is nearly completed.

The Group installed the UNIX-based CEBAF software which will be used to operate the accelerator. This initial installation on one of the Group's Hewlett-Packard computers enabled us to begin to understand the control system logic and commands and has also permitted us to test CAMAC units and systems. With the software installed in the main control computers, we have managed to move the end magnets successfully to demonstrate that the new stepper-motor system employed will work reliably, as well as operate some of the phase shifters.

We await the (delayed) delivery of the new klystron power converter, for which a new controller will be designed. Whittaker attended the CERN Power Converter School, held in Montreux, Switzerland, in the Spring. The School was very good indeed and was really a technical symposium with representatives of all the major laboratories in the world in attendance.

With total involvement with the RTM construction, the Group has not been able to provide the instrumentation services outside the Division for which it was originally formed 33 years ago.

IV. Mechanical Instrumentation (D. Mohr, J. Billos, C. Bostian, J. Bradley, D. Fox, and P. Liposky)

Mechanical instrumentation services were provided for the Center in connection with its particle accelerators and experimental programs. The services consisted of design, construction, and installation of new equipment and facilities as well as maintenance and modification of existing equipment to improve performance and reliability.

Devices that were designed and built this year include: all of the required support structures for the RTM return lines, including the supports for quadrupole magnets Q10-11; extraction beamline dipole magnet D14; and extraction beamline quadrupole magnets Q12-21, which were purchased with a group member serving as Contracting Officer's Technical Representative (COTR). The FEL mirror mounts were designed with an exoskeletal approach chosen as the best method to achieve very accurate motion while at the same time keeping hydrocarbons, motors, and measuring devices out of the high vacuum system. These mounts are capable of holding from one to seven mirrors, any of which could be put on line without interrupting operation. This allows nearly continuous operation over the entire range of wavelengths.

The major focus for construction and installation this year has been the RTM return lines. This includes Q10 and Q11, each of which is a group of 14 individual magnets. These were installed and aligned to ± 25 μm. Magnet D11 was installed and tested over its travel length of approximately 1.2 m. Dipole magnets D12 and D13 were installed. The RTM main axis was modified from one pass test mode to be ready for full RTM operation.

We now have four operational CAD/CAM work stations. These have been essential to the quality of mechanical designs used for the RTM/FEL project. The Mechanical Instrumentation Group has continued to be heavily involved in planning for the RTM/FEL project, serving as COTR or alternate on magnet and undulator procurements.

V. Radiation Instrumentation Standards (L. Costrell)

The Division provides national leadership in standardization concerned with nuclear instrumentation. The standards fall into three categories: National Voluntary Standards, Nuclear Instrumentation Module (NIM) Standards, and International Electrotechnical Commission (IEC) Standards.

The Division plays a leadership role in the development and processing of National Voluntary Standards of the American National Standards Institute (ANSI) and of the Institute of Electrical and Electronics Engineers (IEEE), and participates in the associated policy boards. L. Costrell serves as Chairman of ANSI Committee N42 on Radiation Instruments and as Secretary of the IEEE Nuclear Instruments and Detectors Committee. In these capacities he has processed a considerable number

of ANSI and IEEE standards, serves on the ANSI Nuclear Standards Board and is a member of its Planning Committee.

The NIM Committee, of which L. Costrell is Chairman, oversees development and maintenance of instrument standards in cooperation with the National Laboratories and other major laboratories, primarily for nuclear applications. NIST has management responsibility for this work with L. Costrell serving as Project Manager.

The NIM system[2], initiated by NBS[3], has been adopted nearly universally in the U.S. as well as in all other industrialized nations. A continuous coordination effort is required and is provided, involving contact with numerous laboratories and manufacturers. Similar management, direction and maintenance services are provided in the U.S. with regard to the international CAMAC (Computer Automated Measurement and Control) system[4] that is utilized in the National Laboratories and in a large number of other laboratories and installations throughout the world. A third system for which the Division has management responsibility is the FASTBUS high speed modular data acquisition and control system for high energy physics and other applications[5-9]. The FASTBUS development has been a major effort, with commercial equipment now available and systems in operation or in preparation in numerous laboratories in the U.S., Europe and Japan. Coordination and processing of the specifications is handled by the Division. The standards are initially issued as reports of the U.S. Department of Energy and are later processed as standards of ANSI, the IEEE and the IEC.

The NIM and CAMAC standard instrumentation projects have resulted in a savings in excess of four billion dollars based on extrapolation of the 1.9 billion dollar savings calculated in 1982 by an economics consulting firm in a study conducted for the Department of Energy[9]. The study report states that the 1.9 billion 1982 dollars is considered to be a minimum figure. Since the NIM and CAMAC systems are in worldwide use, the total worldwide savings resulting from these two systems can be reasonably projected to be double the U.S. savings, or in excess of eight billion dollars. Figures are not yet available on the savings resulting from the newer FASTBUS system.

L. Costrell serves as Technical Advisor to the U. S. National Committee of the IEC for IEC Committee TC45 on Nuclear Instruments. He serves as Chief U.S. Delegate to TC45, as Chairman of the Working Group on Detectors and as a member of other working groups. Numerous draft documents were prepared and reviewed, resulting in a number of approved international standards. These include documents that are identical to the NIM, CAMAC and FASTBUS standards. Similarly, the international standards for numerous radiation detectors, radiation measurement instrumentation, test procedures, radiation protection instrumentation, and several other standards are technically identical to ANSI/IEEE standards developed by the committees referred to above.

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4. "CAMAC Instrumentation and Interface Standards," IEEE Publication SHO8482, Library of Congress Catalog No. 8185060 (ANSI/IEEE Stds 583, 595, 596, 675, 683, 726, 758).

5. "FASTBUS Modular High Speed Data Acquisition and Control System," ANSI/IEEE Std 960-1986 (currently under revision).

6. "FASTBUS Standard Routines," ANSI/IEEE Standard STD 1177-1989.

7. "FASTBUS Modular High Speed Data Acquisition System," International Electrotechnical Commission (IEC) Publication 935.

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Division 535, Radiation Source and Instrumentation

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TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 535, Radiation Source and Instrumentation

Louis Costrell

Chairman, NIM (National Instrumentation Methods) Committee

Chairman, American National Standards Institute Committee N42, Radiation Instrumentation

Member, American National Standards Institute Nuclear Standards Board

Member, American National Standards Institute Nuclear Standards Board Planning Committee

Secretary, IEEE Nuclear Instrumentation and Detectors Committee

Ex-Officio Member, IEEE Nuclear and Plasma Sciences Society Administrative Committee

Chairman, IEEE Nuclear and Plasma Sciences Nominating Committee

Chairman, IEEE Nuclear and Plasma Sciences Annual Meetings Committee

Member, Organizing Committee, 1991 IEEE Particle Accelerator Conference
Member, U.S. National Committee of the International Electrotechnical Commission (IEC)

Technical Advisor, U.S. National Committee of the International Electrotechnical Commission (IEC)

Chief U.S. Delegate, International Electrotechnical Commission Committee TC45, Nuclear Instrumentation

Chairman, International Electrotechnical Commission Committee TC45 Working Group 9, Detectors

Philip Debenham

Member, Program Committee, 1991 IEEE Particle Accelerator Conference

Julian Whittaker

Member, ASTM Committee D22 on Sampling and Analysis of Atmospheres

Secretary, Department of Commerce, Bureau of Export Administration, Electronic Instrumentation Technical Advisory Committee

SPONSORED SEMINARS AND COLLOQUIA

Division 535, Radiation Source and Instrumentation

Rolf Bork, CEBAF, "CEBAF Control Software," May 3, 1990.

Dr. Roy I. Cutler, SSC Laboratory, "The SSC Linac," August 28, 1990.

TECHNICAL ANALYSIS OF THE NIST RTM/FEL PROJECT

Prepared By

Philip Morton, Chairman
Richard Briggs
William Herrmannsfeldt
Brian Kincaid
Jerry Watson

Submitted April 20, 1990

SUMMARY

The NIST Race Track Microtron (RTM) accelerator project started about ten years ago with funding from the Department of Energy. The motivation was nuclear physics studies with CW electron beams. The program objectives shifted toward Free Electron Laser (FEL) applications about five years ago when the scientific interest in FEL applications grew, and the interest in RTM technology for nuclear physics diminished. (This loss of interest followed the initiation of the CEBAF project and the adoption of a superconducting rf linac approach to CW electron beam generation.) The objective of the NIST RTM/FEL project is to develop a source of intense, broadly tunable, picosecond pulse formatted photon beams for a broad range of research applications in biology, medicine, and materials. The goal is to construct the device as part of a national user facility.

The RTM has many attractive features as a driver for an FEL. The electron beam emittance and energy spread can be very small, making it possible to operate at very short wavelengths (200 nm) with reasonable gain (i.e., achieve lasing at very short wavelengths). The CW nature of the power source provides for excellent phase and energy stability compared to pulsed rf linac approaches, and the pulse-to-pulse start up problems of the FEL cavity oscillations are avoided. The ability to extract the electron beam after any number of passes through the linac section provides a very broad variability in the electron beam energy, and a corresponding broad wavelength variability of the photon beam from the FEL.

The principal competitor to the RTM technology at this time is a storage ring approach. The broad variability in the electron energy, and the absence of any recirculation of the electrons through the undulator, are distinguishing features of the RTM. Superconducting rf linacs could become an important technological competitor in the future, but the prior investments in the RTM give it the edge as a near term user facility.

The achievement of relatively high peak currents (> 2A) in the micropulses with subharmonic operation is a major focus of the technical development effort. Good progress was made in the design of the injector for high current operation. Calculations indicate that beam transport with these intense pulses should not encounter any difficulties, but some level of uncertainty always exists in accelerators until the actual machine commissioning is underway. The development of low absorption mirrors for UV operation, that are robust against damage by harmonic radiation, is another technical issue being addressed. These issues and others are discussed in the body of the report.

The main concern about the execution of the project is the allowance for adequate time and/or resources to fix the normal set of problems one encounters in the commissioning of a new experimental system on the scale of the RTM/FEL. The project has been severely limited in its funding resources, and the NIST staff has no experienced set of accelerator scientists or engineers available to it from other areas of the lab that it can call on for help, in contrast to the multi-purpose national labs or accelerator labs with many projects. This concern is magnified by the necessity for the project to move quickly to routine operation as a user facility to satisfy the requirements of the sponsor. Delays in the project completion run the risk of disappointing the user community that is essential to secure the funding to complete the development of the radiation source. The NIST management should anticipate the need for seeking outside help for the commissioning of the facility, and it should promote realism in the expectations generated in the user community about the schedule for first operations.

INTRODUCTION

Dr. Wayne Cassatt, Deputy Director of the Center for Radiation Research at NIST has set up a technical review panel consisting of Dr. Richard Briggs and Dr Jerry Watson of the SSC Laboratory, Dr. William Herrmannsfeldt of the SLAC Laboratory, Dr. Brian Kincaid of the Lawrence Berkeley Laboratory and the Chairman, Dr. Philip Morton of SAIC. All of the panel members have received the necessary technical reports and have been briefed on the results and plans of the center. Except for Dr. Kincaid, the panel members have visited the center and met with the staff in February of this year. The charge as given to the panel by Dr. Cassatt follows.

CHARGE TO CONSULTANTS

"The Center for Radiation Research is in the midst of constructing a free electron laser (FEL) and a racetrack microtron accelerator (RTM) that will be the driver for the FEL. We also are seeking substantial funding for the construction of a number of major research laboratories so that the overall complex can be operated as a National Free Electron Laser Facility.

"We feel that this is an appropriate time to bring in a number of experts in certain technical areas to provide us with assistance in the final analysis of the design of critical elements that remain to be completed in the RTM and FEL.

"Therefore, we request your assistance in the form of a technical analysis and recommendations regarding the design, construction, and project management of the following:

"1) The RTM electron accelerator, especially
- the high current injector gun
- the new chopper, buncher that prepares the high current pulsed electron beam for the preaccelerator
- high current beam diagnostics
- the beam behavior calculations
- the control system for the accelerator
- the main klystron power supply system

"2) The free electron laser, especially
- the undulator and its controls
- the laser cavity, its mirror systems and controls (including mirror changer)
- the performance calculations
- the FEL control system

"3) The electron beam transport system, especially
- beam optics design
- the focusing elements
- the vacuum system
- the diagnostic elements
- the control system

"4) The photon beam transport system
- beam optics design

- the optical elements, their supports and positioners
- the vacuum system
- the control system

"We are particularly interested in any suggestions that will:
- Enhance the performance parameters of the FEL/RTM
- Increase the probability of successful completion and operation
- Accelerate the construction of the facility in a cost effective manner
- Enhance the efficiency and cost effectiveness of operation
- Enhance the reliability and ease of maintenance"

OVERVIEW

The FEL project uses an electron beam from the race track microtron (RTM) at NIST passing through a 130 cell undulator. The RTM is designed to recirculate the electron beam, injected at 5 MeV, through a side-coupled 12 MeV accelerating structure up to fifteen times. It is possible to obtain electron energies from 5 MeV up to 185 MeV in steps of 12 MeV. The magnetic field in the undulator is to be varied by changing the gap of the undulator from 1.4 cm to 0.84 cm. A combination of different electron energies and undulator gap allows a tunable wavelength range for the laser beam from 200 nm to 10 μm in a train of microbunches at a repetition rate up to 66 MHz.

The original microtron was designed to operate with a continuous beam of 3 ps-long microbunches at 2380 MHz with 0.25 pC or 1.5×10^6 electrons per microbunch. Because this beam does not have sufficient peak current to supply the necessary gain for the FEL, a new injector will be installed to supply 14 pC or 9×10^7 electrons per microbunch. The 3 ps-long microbunch of will have a repetition rate of 16.5 or 66 MHz to match the round trip period of the light between the mirrors in the FEL of 1/16.5 MHz.

For successful operation of a CW FEL the main requirements are:

1. A sufficient peak current to obtain the required gain.

2. Optical cavity losses including output coupling must be less than the gain.

3. The transverse emittance of the beam must be small enough so that both the electron and photon beam overlap in the transverse direction. The spread in the longitudinal velocity of the electrons due to the transverse emittance must be less than the portion of the gain band width where the gain exceeds the optical cavity loss.

4. The spread in the longitudinal velocity due to the energy spread also must be less than the same portion of the gain band width.

5. The quality of the undulator field must be sufficient to meet the same conditions as in item 3.

6. The length of the electron microbunch and the timing jitter between the electron microbuncher must be restricted to make sure that the beams overlap in the longitudinal direction.

The RTM design is better able to satisfy the emittance and energy spread requirements of items 3 and 4 at the desired energy range than any other accelerator. The design current and mirror reflectivity of the NIST design are sufficient satisfy the gain/loss requirements of items 1 and 2, but there is not a large margin at the shorter wavelengths. It is important to have good quality control and good diagnostics to be able to satisfy these requirements. There is no reason to doubt that the NIST design of a race track microtron driven FEL can be built to satisfy all of these requirements, but special attention must be given to obtain the necessary gain/loss ratio.

MANPOWER AND BUDGET PROJECTIONS

The panel feels that the quality of the project staff is well balanced with a good range of capabilities, however, the recent loss of S. Penner and R. Cutler have left a gap that needs to be filled. The quantity of the staff is barely sufficient to allow the project to be completed on the present schedule. In particular, NIST produces most of its own hardware rather than purchasing it directly. In addition to a financial savings, this has the advantage that the staff will be knowledgeable about the performance of all of the components; however, it does place a significant demand upon the available manpower. Both the budget and the proposed schedule only allow for minor contingencies and if unforeseen problems occur the schedule will slip. Should this occur NIST has several possible solutions:

1. Increase staff (in particular, replace lost staff). This would require some advance notice of the need.

2. Buy hardware outside as much as possible. Again this requires some lead time.

3. Team with others as much as possible (industrial job shoppers, other National Laboratories, University of Maryland, etc.). This already has been done to a slight extent with the collaboration of NRL, and has the advantage of a minimum time response.

4. Bring in graduate students for thesis work on the design of the RTM or FEL.

Clearly these steps will increase the cost but could be used to help preserve the schedule.

ION TRAPPING

In high current CW FELs and electron storage rings there is a problem with the ions produced by collisions with the background gas, being trapped by the electron beam. We have looked at this problem for the NIST design. An ion of mass number 20 at the edge of a 1 mm beam will receive a transverse velocity kick from the electron pulse of 14 pc of 4 m/sec. This will produce a transverse displacement 62 ns later, when the next microbunch passes, of less than 1/3 μm. To treat the problem of ion trapping we can ignore the microbunching of the beam and assume that it is continuous with an average current of less than 1 mA. The potential between the center of the electron beam and the wall is given by

$$V = 30\ (\text{mV/mA})\ I\ [1 + 2\ \ln\ b/a]$$

where I is the average current, b the wall radius (we assume it is 1 cm) and a the beam radius (we assume it is 1 mm). Thus the trapping voltage is less than 200 mV so it does not seem to be an important problem in the return lines or the undulator. In the accelerator cavity the current is 15 mA and the trapping voltage 3 V, but there are large electric fields present that will sweep the ions to the wall.

HIGH CURRENT INJECTOR FOR RTM

The principal, new, large cost procurement remaining for the RTM is the High Current Injector (HCI). This is also the critical item on the schedule for delivering light. Procurement began in the spring of calendar 1990 with delivery and/or completion of (in-house) construction in the second half of 1991. Installation is scheduled to be complete by the end of 1991 so that FEL commissioning can begin in January 1992.

Total budgeted costs for the HCI are $780,000, about $270,000 in fiscal year 1990 and the balance in fiscal year 1991. It is apparent that meeting the schedule for the FEL (commissioning in the first half of 1992) depends absolutely on obtaining and committing those funds in 1990 and 1991.

Requirements for the HCI were documented in a note (Debenham, FEL Design Note #14) entitled "Emittance Specifications for a New 5 MeV RTM Injector." This note determines the requirements based on anticipated needs for FEL performance and backing out anticipated sources of emittance growth. The opposite approach, i.e., starting from the gun and making PARMELA calculations through the 5 MeV preaccelerator, was presented in the review briefing. The FEL requirements were determined in the usual way, i.e., the transverse emittance (unnormalized) is less than λ/π, where λ is the desired photon wavelength, and dp/p less than 1/2N, where N is the number of undulator periods. A tighter specification on dp/p results from the longitudinal bunch length requirement of about 3.5 ps. The required and calculated emittances are tabulated below:

	Required Emittance		Calculated Emittance	
	En	Ez	En	Ez
2A (Q=7 pC)	5 μm	20 keV-deg	4.3 μm	17 keV-deg
4A (Q=14 pC)	9	36	6.1	34
CW (Q=.25 pC)	1	5	0.7	5

The third line in the table, for low charge CW operation, is presented for comparison with present experience. A new chopper-buncher system has been proposed which should at least equal, and probably improve on those results. Although the calculated emittances are very close to the required values, we were told that a newer version of PARMELA, with more accurate emittance algorithms, will find lower emittances. Thus these calculations have at least some degree of conservatism.

The RTM-FEL project has abandoned the previously announced plans to use a laser-photocathode injector. There was concern about cathode life time and meeting the phase and amplitude stability requirements. The review panel concurs that the proposed thermionic injector should meet the design goals and is the more appropriate choice for this mission.

DIAGNOSTICS

The planned electron beam diagnostics for the commissioning and operation of the RTM appear to be adequate for proper position and phase control. The use of wire scanners, phosphor screens, and resonant-cavity detectors at appropriate locations has been well thought out and the devices are being engineered for good reliability with the high average current.

BEAM BEHAVIOR

The onset of beam breakup (BBU) at an average current near 500 μA is a possibility if the bunches are not precisely kept on axis through the accelerator. Operation at 66 MHz could have a lower BBU threshold since energies and phases of the different passes will vary about the design values because of different beam loading. This may make it difficult to align all of the passes precisely on the axis (therefore exciting the TM 110 modes). There is also some concern that the resulting longitudinal oscillations may couple to instabilities. Initial tune-up at 16.5 MHz should avoid these problems, since there would never be more than one bunch in an accelerator cavity at any instant. Good performance at 66 MHz may require extensive steering corrections or small corrections coils in the end magnets that are separately tuned for each return line.

Since energy jitter at 66 MHz is expected, we recommend that the potential effects of this be studied in much more detail. The BBU thresholds for 66 MHz and 16.5 MHz should also be reevaluated including this effect.

UNDULATOR

One of the sub-systems that is critical to the success of the project is the undulator magnet. The specifications for the undulator system have been defined correctly and carefully. In this regard, the theoretical support from the NRL group has obviously been of great value and is an important positive contribution to the project. It should be emphasized that the field error tolerance specifications that have been set for the outside contractor for the magnet are correct and necessary for the proper operation of the FEL. They are not overly conservative and, therefore, should not be compromised for the sake of schedule or because of other technical difficulties.

All available evidence indicates the magnet contractor has a talented technical team working on the device. The mechanical design of the magnet support and drive system appears excellent. The contractor team seems to be able to make high quality magnetic field measurements on the undulator its team has built. The problems the team has been having meeting the required field tolerances may be considered to be "teething troubles" related to their inexperience in the field of high precision undulators. The NIST RTM/FEL group and the magnet contractor should establish, by mutual agreement, a regular communication, in the form of progress reports and actual magnetic field data, so that NIST can be assured that progress is being made, and so that the contractor can benefit from the NIST group's analysis of any technical problems. In this area, the NIST group should seek outside assistance from other undulator and FEL experts, if necessary.

A system for checking the field quality of the undulator in-house could be useful. Such a system would be a good part of overall quality assurance. Experiences with other linac-based FEL systems indicate that it is possible for a mis-steered electron beam to damage the permanent magnet

undulator by heating and radiation dose. Some kind of diagnostic measurement system and magnet protection interlock system should be provided.

On the whole, the undulator project seems to be in good shape technically.

CONTROL SYSTEM

The acquisition of the new control system was necessary to provide the expansion needed for the FEL controls and also the ability to utilize commercially available CAMAC modules. The choice of the CEBAF control system appears appropriate since control and monitoring screens can be readily configured. The installation and check out of a new control system is a large effort, and additional support may be required for it to be ready for the next RTM operation. It is also felt that plans to implement some automatic control algorithms should be started. Eventual routine and reliable operation of the FEL may rely on the use of some automatic controls.

Rf POWER SYSTEM

The overall design and engineering of the klystron system and the power distribution appear to have been well done. The primary problem has been the reliability of the commercially acquired power supply. It has slowed RTM operational progress by many months on several occasions. The purchase this year of a new power supply should improve operational reliability very substantially.

SUGGESTIONS

Since there is no slack in the schedule the panel feels that the following suggestions would help to meet the schedule.

1. Set up and test the optical resonator early to understand and diminish losses. Unexpected losses lead to need for higher circulating power in the cavity, which could lead to mirror damage and the need for a higher electron beam current.

2. Set up a system that doesn't require extensive down time to check the undulator for degradation. Have a good bench mark for undulator field quality before any beam is injected into the undulator. The pulsed wire technique developed at LANL should be good for NIST's undulator parameters and provides routine monitoring by storing the wire in the bottom of the vacuum pipe.

3. Provide adequate experimental and theoretical support for an extended period for commissioning. The commissioning team must be totally dedicated to that effort and not have other diversions during the commissioning period. Microtrons and FELS are not simple to commission.

TECHNICAL ACTIVITIES

Division 536, Ionizing Radiation

The functions of the Ionizing Radiation Division may be summarized as follows:

- Provides primary national standards, dosimetry methods, measurement services, and basic data for applications of ionizing radiation (x rays, gamma rays, electrons, neutrons, and radioactivity, etc.) in such areas as:

  - Radiation protection of workers and the general public
  - Radiation therapy and diagnosis
  - Nuclear medicine
  - Radiography
  - Industrial radiation processing
  - Nuclear energy
  - National defense
  - Environmental protection

- Conducts theoretical and experimental research on the fundamental physical and chemical interactions of ionizing radiation with matter to provide the competence for:

  - Developing improved understanding of the physical stage of the interaction of ionizing radiation with matter
  - Developing an understanding of basic mechanisms involved in radiation-induced chemical transformations and the parameters that influence the yields of short-lived intermediates, final chemical products, and biological effects
  - Developing improved methods for radiation measurement, dosimetry, and radiography
  - Developing improved primary ionizing radiation standards
  - Producing highly accurate standard reference data for ionizing radiation and radioactive materials

- Provides essential standards and measurement support services to the National Measurement Support System for Ionizing Radiation that provides calibrations and measurement quality assurance services to:

  - Medicine
  - Industry
  - States
  - Other Federal Agencies

Division 536, Technical Activities (cont'd)

- Develops and operates well-characterized sources of electrons, photons, and neutrons to provide:

  - Primary radiation standards and fields
  - Well-characterized beams of radiation for research on radiation interactions and for measurement methods development.

The current organizational structure of the division consists of four groups:

Ionizing Radiation Division (R. S. Caswell, F. J. Schima)

Office of Radiation Measurement (B. M. Coursey, acting)

Radiation Interactions and Dosimetry (B. M. Coursey)

Neutron Interactions and Dosimetry (J. A. Grundl)

Radioactivity (D. D. Hoppes)

Three high priority research areas we wish to strengthen are:

- Measurement of New Radionuclides for the Radiopharmaceutical Industry
- Free Radical Measurements in Biosystems by Electron Spin Resonance
- High-Energy Electron and X-Ray Dosimetry Research for Medical Radiation Therapy

For the last of these areas, and for our research in industrial radiation processing and pulse radiolysis, we have a high priority need for a "push-button" electron linear accelerator of about 40 MeV maximum energy, capable of both high currents and nanosecond pulse operation. This need is created in part by the shut-down of the racetrack microtron (RTM), which would have been a suitable source for the high-energy dosimetry research.

I. Office of Radiation Measurement

The function of the Office of Radiation Measurement (ORM) is to promote the dissemination to federal, state, and local radiation control programs, and to the medical, industrial, and defense communities, of the measurement standards and technology required for reliable measurement of ionizing radiation. The Office assists the technical groups of the Ionizing Radiation Division in monitoring and evaluating the radiation measurement needs of these national user groups, and in research, metrology development and quality control activities undertaken to meet national needs. The latter include methods for improving the consistency of field measurements with the national physical measurement standards through a national system of secondary standards laboratories. The Office maintains liaison and participates in collaborative measurement quality assurance programs with organizations that conduct measurement-intensive programs in the areas

of radiation safety, energy, health, and contamination of the environment. Examples are the Nuclear Regulatory Commission (NRC), Department of Energy (DoE), Food and Drug Administration (FDA), Environmental Protection Agency (EPA), Health Physics Society (HPS), and the Conference of Radiation Control Program Directors (CRCPD).

Primary and Transfer Standard Phantoms for In-Vivo Radioactivity Measurement Quality Assurance and Accreditation Programs (K. G. W. Inn)

A keystone for implementation of a national voluntary laboratory accreditation program for in-vivo radiobioassay is the development of primary and transfer standard phantoms for calibrations and proficiency testing. In February 1990 the Office of Radiation Measurements and the Bureau of Radiation and Medical Devices (Canada), with co-sponsorship with the U.S. NRC and the U.S. DoE, conducted a workshop of national and international experts to explore the barriers for the creation of standard radioactivity phantoms. The outcome of the workshop was a detailed list of research and development recommendations and short and long term goals for the development and refinement of torso, bottle, thyroid, and bone phantoms. A proposed five-year plan based on these recommendations and goals, and multi-agency coordination is being organized through CIRRPC.

State-Operated Calibration Laboratories (M. D. Walker, H. T. Heaton, & K. G. W. Inn)

Both the South Carolina and Illinois Laboratories moved to new facilities. A visit was made to the South Carolina laboratory to assist them in preparing for accreditation. Illinois personnel visited NIST in order to become more familiar with the ORM computer code, which is used for characterization of the laboratory. The Illinois, as well as the South Carolina laboratories are hoping to apply for accreditation by the Spring of 1991. The Radiation Measurements Committee visited the California laboratory in order to make recommendations in reference to the laboratory's accreditation approval.

Federally-Owned Calibration Laboratories (J. C. Humphreys, E. H. Eisenhower, K. G. W. Inn, & H. T. Heaton)

There are about 10 potential laboratories that could participate in this program from agencies such as FDA, DoE, DoD, NRC, and FEMA. The accrediting organization for these laboratories will be the National Voluntary Laboratory Accreditation Program (NVLAP) at NIST under its Secondary Calibration Laboratories for Ionizing Radiation program. The consensus criteria document for performance and testing of these laboratories gained final approval and is ready for implementation. A checklist for use by NVLAP Technical Experts as part of the assessment of each laboratory was also approved. Initial applications for the program are expected in January 1991. Proficiency tests and on-site evaluations for the various radiation programs at the federal laboratories will be conducted by ORM staff as part of the accreditation process. The types of programs include calibration of survey, diagnostic, and reference instruments, source calibration, and personnel dosimeter irradiations.

Personnel Dosimetry (J. C. Humphreys, M. D. Walker, K. C. Duvall, & H. T. Heaton)

Calibrated transfer ionization chambers were supplied to the testing laboratory used in the NVLAP Personnel Radiation Dosimetry program. The exposure and exposure rates for some of the laboratory's x-ray beams were intercompared with those of NIST. The results were satisfactory within the uncertainty limits. Research was performed to determine the suitability of selected types of TLDs for use as neutron dosimetry transfer standards. This work included the characterization of the reproducibility, stability, and relative gamma-neutron sensitivity of the response of the TLDs. In addition, the merits of the use of a commercial remmeter as a transfer neutron dosimetry system were examined. It has the advantage of providing information on the relative hardness of the neutron spectrum. The NIST beta dosimetry calibration capabilities were significantly improved by the acquisition of a set of calibrated beta-particle sources and a specially-built extrapolation chamber. This enables NIST to provide high-accuracy calibrations of beta sources or appropriate transfer ionization chambers submitted by outside users.

Transfer Standard QC Facilities (H. T. Heaton & M. D. Walker)

A 0.11 TBq (3 Curie) ^{137}Cs pneumatic source was installed in the ORM gamma-ray facility to replace the manually-operated one. Ongoing intercomparisons continue with the Radiation Interactions and Dosimetry Group in order to maintain quality assurance procedures for the ORM.

American Association of Physicists in Medicine (AAPM) Accredited Dosimetry Calibration Laboratories (ADCLs) (P. J. Lamperti & B. M. Coursey)

Task Group 3 of the AAPM is a standing committee which accredits secondary dosimetry calibration laboratories for the radiation therapy community. The five ADCLs this year participated in a round robin intercomparison of two ionization chambers provided by the NIST dosimetry group. A Victoreen 415A thin-window low-energy chamber and a Shonka chamber (3-cm^3 air equivalent plastic) were used for selected x-ray beam qualities, ^{137}Cs and ^{60}Co. Participants' results were within $\pm$ 1 percent for all but a single chamber and beam quality for one laboratory. A follow-up measurement with NIST on another chamber resolved this discrepancy. NIST provided consultation to the ADCLs on a number of standards measurement issues, including high-dose-rate ^{192}Ir brachytherapy calibrations and $^{90}Sr+^{90}Y$ ophthalmic applicators.

High-Dose Calibration Laboratory (J. C. Humphreys & E. H. Eisenhower)

ASTM subcommittee E10.01 on Dosimetry for Radiation Processing has developed a new standard entitled "Practice for the Characterization and Performance of a High-Dose Gamma Radiation Dosimetry Calibration Laboratory." This practice is nearing final approval and should be available shortly. It will serve as the basic plan for accreditation of laboratories that provide calibration services to industry and federal labs involved in radiation processing (such as sterilization of medical products, modification of polymers, or hardness testing of electronic devices). Detailed performance and testing criteria, such as that just approved for the federally-

owned calibration laboratories, are still needed. The accrediting organization has not yet been determined.

II. Radiation Interactions and Dosimetry

This Group carries out a wide range of programs in radiation sciences and dosimetry of x-rays, gamma-rays, and electrons. The mission for the Group is to develop, maintain and disseminate the national standards for these radiations, and to engage in research on radiation interactions and effects to meet requirements for new standards. The Group's activities are presently divided into four projects: radiation sources; physical interactions and dosimetry; chemical interactions and dosimetry; and radiation measurement services.

The Radiation Sources Project consolidates the operation, maintenance, and updating of the electron, x-ray, and neutron-producing sources of the Division. These sources when combined with the high precision x-ray generators used for dosimetry and calibrations and a large number of radioactive sources are the backbone of the experimental programs of the Division.

The Physical Interactions and Dosimetry Project encompasses experimental, theoretical, and computational research and metrology. The four programs in this project are: theoretical dosimetry, medical dosimetry, radiation protection dosimetry, and x-ray imaging. The Chemical Interactions and Dosimetry Project has two programs: radiation and oxidative biochemistry, and chemical dosimetry. Many of these programs are interdisciplinary, and the four Ph.D. physical chemists in the Group help coordinate extension of traditional physical dosimetry systems (ionometric, calorimetric) to dosimetry systems based on chemical changes in materials (spectrophotometric, ESR, and biochemical).

The Radiation Measurement Services Project combines the calibration services and measurement assurance programs for industrial, medical, military, and personnel protection applications. The project also includes technical support for measurement assurance programs in dosimetry and radiographic imaging.

A. Radiation Sources Project (C. E. Dick, M. McClelland, R. J. Biss, & J. L. Mills)

This project aims at the consolidated operation and maintenance of the major radiation sources of the Radiation Interactions and Dosimetry Group. These sources include 3 electron accelerators (0.5, 1.5, and 4 MeV), 2 high power x-ray sources (300 and 420 keV) and two positive ion accelerators (0.1 and 3.0 MeV). In addition, consulting and supplementary services are provided for the 2 MeV flash electron accelerator and for a number of radioactive sources. This arrangement which was initiated in FY89 has provided a cohesive mechanism for the efficient operation of these sources.

In the past year, a number of modifications and improvements have been made to the sources. The 420-keV x-ray source has been installed and is now fully operational. Preliminary installation of equipment for experiments in quantum metrology and x-ray production has begun. A new ion optics lens system was designed and installed on the 3-MeV positive ion accelerator.

This system is designed to provide higher beam currents and tighter beam focussing. Evaluation of this system is now underway. New safety interlocks have been designed and installed on the vertical beam radioactive sources. In addition, this project has assumed responsibility for the 100-keV ion accelerator used for neutron production. This machine is being refurbished and should be operational in the first quarter of FY91.

B. Physical Interactions and Dosimetry Project

1. Theoretical Dosimetry

The general objective is to carry out studies of radiation interactions with matter, and of radiation transport in bulk media, in order to generate basic radiological physics information in areas including biomedical radiation dosimetry, assessment of radiation hazards in nuclear technology, modeling of biological radiation action, radiation metrology and source characterization, space shielding, auroral physics and space science, and industrial and military technology. This work includes the development of transport-theoretic methods, the compilation and critical evaluation of the underlying single-scattering cross sections, and the application of the transport methods to radiological physics problems.

Electron and Positron Elastic Scattering Cross Sections (M. J. Berger & S. M. Seltzer)

A computer-readable database has been completed of elastic-scattering cross sections for electrons and positrons incident on atoms with atomic numbers $Z = 1$ to 100. The data are from calculations based on a relativistic partial-wave expansion, using Hartree-Fock potentials, and provide sufficient coverage to allow for accurate interpolation to all angles and any kinetic energy from 1 keV to 1 MeV (above which simpler methods can be used). To incorporate these elastic-scattering cross sections into our transport codes, methods have been developed for the numerical evaluation of the Goudsmit-Saunderson distribution of plural- and multiple-scattering angular deflections. The Goudsmit-Saunderson distribution is formally exact and, used in conjunction with the new "exact" single-scattering cross sections, should provide more reliable distributions. Test calculations for the transmission and reflection of electrons by foils show significant differences compared to the use of more-approximate cross sections, particularly at low energies in high-Z absorbers.

Monte Carlo Code Development (S. M. Seltzer & M. J. Berger)

Improved algorithms for the NIST general-purpose electron-photon transport Monte Carlo code ETRAN have been developed in the following areas: the treatment of binding effects on the incoherent scattering of photons from atomic electrons, and of coherent photon scattering from the screened nuclei of the atomic constituents; the treatment of multiple and plural elastic scattering of electrons and positrons; corrections to the sampling of electron and positron energy-loss fluctuations; the treatment of fluctuations in the transverse and longitudinal displacements in the multiple-scattering charged-particle random walk; and the treatment of other processes in positron transport (annihilation in flight, knock-on production, and bremsstrahlung production).

Differences in the Transport of Electrons and Positrons (M. J. Berger)

A study has been done on the differences between electron and positron penetration in Al, Ag, and Pb foils, for incident particle energies from 2 MeV to 10 keV. The differences between the scattering cross sections for electrons and positrons lead to differences in number and energy transmission and reflection: positron transmission is greater, and reflection smaller, than that for electrons of the same energy. The results were presented at the Symposium on the Physics of Electron Transport held at NIST, April 2-3, 1990.

Computational Cobalt-60 Dosimetry (S. M. Seltzer)

For purposes of assessing energy response of detectors used to monitor the dose in radiation processing, Monte Carlo calculations were done of the photon fluence (unscattered and scattered) at various depths in a unit-density water product irradiated by a large ^{60}Co plaque source assumed comprised of AECL Type C-188 source pencils. The fluence spectra were then used to calculate the ratio of the absorbed dose in various thick dosimeters to that in the water product; dosimeter materials of C, LiF, $Li_2B_4O_7$, SiO_2, PMMA, nylon, and alanine, and of ferrous sulfate, ceric sulfate, K-Ag dichromate, and ethanol-chlorobenzene solutions were considered. A paper describing this work was presented at the 7th International Meeting on Radiation Processing and has been published in the Journal of Radiation Physics and Chemistry.

Auroral Bremsstrahlung Calculations (S. M. Seltzer & R. A. Broadhurst)

Extensive Monte Carlo calculations of the bremsstrahlung flux produced by electrons slowing down in air have been done for a NASA project to characterize auroral bremsstrahlung phenomena. The generated information includes the electron and photon fluence distributions (differential in energy and angle) and the energy deposition as functions of altitude in the Earth's atmosphere, from auroral electrons with initial energies from 2 keV to 20 MeV. To reduce this information to a database that is interpolable in each of the many variables requires extensive smoothing, scaling, and fitting of the statistically noisy Monte Carlo data. Interactive software, using least-squares and natural splines, is being developed for our graphics workstation to aid in this task.

Bremsstrahlung Calculations for a Cold-Fusion Cell (S. M. Seltzer)

The cold-fusion cells used by Pons and Fleischmann were monitored for 5 weeks with a NaI detector in Pons' laboratory at the University of Utah. The gamma-ray signals were interpreted in terms of the four known possible fusion channels. For one case, the bremsstrahlung flux emerging from the cell, produced by the internal-conversion electron from the $d(d,\bar{e})^4He$ reaction, was calculated with the ETRAN code; a fit to the measured data indicated an upper limit of 10 nW for the fusion power level for this channel. The upper limit for any of the channels was found to be less than 10^{-6} W. This work, done in a collaboration led by members of the Physics and the Nuclear Engineering Departments at the University of Utah, was reported in Nature.

Proton and Alpha Particle Stopping Powers and Ranges (M. J. Berger)

As part of the work of the ICRU Stopping Power Committee, a manuscript has been completed giving extensive tables of proton and alpha-particle stopping powers (electronic and nuclear), ranges and penetration depths for elements and compounds of dosimetric interest, covering the energy region from 1 keV to 10000 MeV for protons and to 100 MeV for alpha-particles. This work incorporates, and discusses in some detail, current theoretical and experimental information on heavy charged-particle stopping powers.

Stopping power and range tables for protons and alpha particles are presented, with emphasis on materials of interest in radiological physics and biomedical dosimetry. A description is given of the methods used to evaluate the stopping-power formula and its corrections at high energies, to select among experimental data at low energies, and to combine these results into the final tables. The report also includes descriptions of many methods used for stopping-power measurements and a survey of the experimental literature with references to more than 450 papers. A computerized database of the proton and alpha particle tables has been developed for the PC.

Photon Energy Absorption Coefficients (S. M. Seltzer, J. H. Hubbell, & M. J. Berger)

Radiation effects due to photon irradiation take place largely through the interaction of the secondary electrons with the medium. The average absorbed dose is related to the photon fluence by the energy-absorption coefficient, so it is essential to have available accurate values of these coefficients. The last comprehensive evaluation of photon energy-absorption coefficients was done in 1972. The complete re-evaluation of the energy-absorption coefficient is well underway, taking into account the improved cross-section information on scattering and absorption that has accumulated in the last twenty years. Particular attention has been given to the accurate calculation of energy escape due to annihilation in flight of positrons, bremsstrahlung emission by secondary electrons, and x-ray emission following photoelectric absorption. The result will be a computer database and code system with which the energy-absorption coefficient can be easily evaluated for any desired material.

Photon Cross Sections (J. H. Hubbell)

A number of current topics pertaining to the evaluation of photon interaction cross sections and to the use of photon beams have been addressed. An annotated and indexed bibliography of experimental photon-attenuation coefficients for compounds has been published in NISTIR 90-4282 (1990). A report in Acta Crystallography on the International Union of Crystallography X-ray Attenuation Project gives the results of recent experimental determinations of the mass attenuation coefficient of carbon for photons with energies from 6 to 60 keV, and discusses the problems associated with such measurements. The average L-shell fluorescence yields for elements with atomic numbers from 56 to 92 have been evaluated, and the results published in Nuclear Instruments and Methods. A survey of industrial, agricultural, and medical applications of radiometric gauging and process control will soon appear in the NIST Journal of Research.

Electromagnetic Interactions with Nuclei (L. C. Maximon)

Research is underway in two subjects related to electromagnetic interactions with nuclei. The first pertains to the analysis of high-accuracy measurements of electron scattering from nuclei at intermediate and high energies. Such analysis requires accurate expressions for the corrections which must be made to the data before they can be compared with theory. These include radiative corrections, thick target bremsstrahlung, Landau straggling and recoil, and relativistic effects. Current research concerns the inclusion of Coulomb corrections to these electromagnetic interactions, required particularly for the analysis of electron scattering from heavy nuclei. The second area concerns the electron-bremsstrahlung production cross section. One of the most useful probes for the investigation of the properties of atomic nuclei is a quasi-monochromatic beam of polarized or unpolarized photons. These are currently produced by the photon-tagging technique, in which one detects the electron after bremsstrahlung to determine the emitted photon energy. Current work involves the theoretical analysis of these photons in the coordinate system which is directly applicable to the experimental situation (the incident electron beam direction as the primary axis), providing analytic expressions for the use of experimenters.

2. Medical Dosimetry

National standards for therapeutic uses of ionizing radiation are based on instruments and radiation beam facilities maintained at NIST. The major radiation therapy modalities are 1) radiation beams (both ^{60}Co and megavoltage photons and electrons from accelerators), 2) radiation sources (photon sources such as ^{125}I and ^{192}Ir for brachytherapy, ^{90}Sr beta-particle sources for surface tumors); and 3) radiolabelled therapeutic drugs (^{186}Re-labelled bone agents, ^{90}Y-labelled monoclonal antibodies). Radiation beams account for greater than 90% of patient treatments, and NIST has had a program for over 40 years to provide exposure (Roentgen) and now air kerma and absorbed dose (Gray) standards. Development of national standards for brachytherapy and dosimetry for radiolabelled drugs depends strongly on the radiations of the radionuclides employed. NIST priorities in developing national dosimetric standards are set in consultations with outside groups, such as the Radiation Therapy Committee of the American Association of Physicists in Medicine (AAPM).

NIST High-Purity Water Calorimeter for Radiation Absorbed Dose Measurements (S. R. Domen)

A new ^{60}Co teletherapy source 400 TBq (12 kCi) was installed in December 1989. Its high activity permitted the start of precise and accurate measurements for investigating a high-purity water calorimeter to determine its potential of becoming a reliable national measurement standard of absorbed dose. Approximately 1,000 calorimetric runs showed that the measurements of absorbed dose are satisfactorily reproducible over long periods of time, and with five different water fillings. The daily measurements were reproducible within 1 percent standard deviation. The five average values of the measurements with the different water fillings have a standard deviation of 0.25 percent. Following a new filling with water, initial irradiations of only about 5 Gy to 30 Gy were required to produce the reproducible measurements. Such a "cleanup" period is predicted theoretically and has been observed by others. In the present investigation, the measurements showed that cleanup periods on following days were not required. The results

are in good agreement with those determined with a graphite, a graphite-water, and a polystyrene-water calorimeter, which indicates that there is no significant heat defect in the high-purity water calorimeter. Intercomparative measurements with other national standards laboratories are planned for the coming year.

Dosimetry of High-Energy Photon and Electron Beams (L. J. Goodman, C. G. Soares, & R. Loevinger)

Based on an evaluation of commercially available water phantoms, a system suitable for studying the profiles of high-energy photon and electron beams was chosen and ordered. The system consists of an acrylic water tank with a remotely controlled, three-dimensional positioning apparatus; hardware and software to manage the system and control the generation of the required beam scans; radiation dosimeters consisting of one ionization chamber and one solid-state diode dosimeter; a dual-input electrometer amplifier; and all cables and other miscellaneous components. The system was assembled and tested using simulated ionization-chamber input signals to verify proper operation. The apparatus was found to respond correctly to controller commands and to be capable of producing cross-axis and depth-dose beam scans from preprogrammed computer routines.

Wide-Angle Free-Air Chamber (WAFAC) for Iodine-125 (R. Loevinger)

The present NIST standard for ^{125}I brachytherapy sources is probably in error by some amount, perhaps up to 10 percent. In order to provide a primary standard for ^{125}I and other small sources with photon energies below 35 keV, a new type of instrument has been developed. It differs from a conventional free-air chamber in several respects: the electric field is parallel instead of perpendicular to the beam direction, the beam traverses entrance and exit plastic films that are electrodes, and the instrument accepts a beam with a solid angle about 65 times larger than the existing NIST standard free-air chambers.

The WAFAC was constructed at NIST and following testing was compared with a NIST air-kerma standard, the Ritz free-air chamber. The following table gives the ratio of the charge per unit volume in the Ritz chamber to the charge per unit volume in the WAFAC, using three different chamber lengths, in the form of per mille (parts per thousand) difference from unity. A positive number indicates that the Ritz chamber gave the larger reading.

Length (mm):	40	75	150
Beam code			
M20	4	5	8
M30	2	-2	-6
H30	4	7	2
L40	4	8	4

The mean difference is 3.4 $\pm$ 1.1 (1 σ) per mille. This might indicate that the measured diameter of the lead aperture is 0.17 percent too large. This translates to an error of 15 μm = 0.015 mm, which probably cannot be improved on, considering that the edges of the aperture are slightly rough. The agreement between the Ritz chamber and the WAFAC is within the range of

agreement shown by national primary air-kerma standards when compared at the Bureau International des Poids et Mesures (BIPM) laboratory.

Brachytherapy Sources (L. J. Goodman)

The use of the radionuclide ^{125}I is expanding rapidly for the interstitial, intracavitary, and intraluminal treatment of tumors. A new calibration service for ^{125}I seeds is being developed which will use the newly constructed wide-angle free-air ionization chamber (WAFAC) to measure the air kerma of individual sources in free air. These seeds will then be used by secondary calibration laboratories to calibrate the reentrant ionization chambers which are used to measure the strength of the ^{125}I seeds actually used in patient treatments. A special fixture for suspending an ^{125}I seed in free air with minimal attenuating and scattering materials is being designed. This will be used in a new facility, also being designed to provide suitable positioning and shielding for these calibrations.

Brachytherapy Dosimetry for Treatment Planning (W. L. McLaughlin, B. M. Coursey, C. G. Soares, M. L. Walker, & J. M. Puhl)

One of the most difficult radiotherapy modalities to carry out accurately is brachytherapy, where typically gamma-ray emitting radionuclide sources (e.g. ^{192}Ir) are implanted in tissues near tumors in a carefully chosen geometry. An innovative breakthrough in treatment-planning dosimetry has been achieved in a collaboration between NIST and the Department of Therapeutic Radiology of Yale University. This involves the use of radiochromic dye films to measure high-resolution dose distributions in three dimensions in anatomical phantoms simulating regions near lesions to be treated. Another challenge is to increase the accuracy of the dose mapping by assessing the photon-energy dependence of the dosimeter film sensor. The goal of this work is to measure absorbed dose at a given point in tissue to within ± 5 percent. A joint paper has been submitted to Medical Physics.

Beta-Particle-Emitting Ophthalmic Applicators (C. G. Soares)

A thorough review of the use of extrapolation chambers to measure surface absorbed-dose rate from $^{90}Sr+^{90}Y$ ophthalmic applicators was completed. This work resulted in a major revision of the NIST method for performing such calibrations. The major changes involved using a collecting electrode smaller than the source being calibrated, and restricting measurements to air gaps less than 0.20 mm. These changes yield current-versus-air-gap data that are linear and which extrapolate unambiguously to zero air gap. Additional investigations involved changes in the recombination corrections used, stopping-power averages and corrections for electrode backscatter. A paper describing the changes to the NIST procedure has been submitted to Medical Physics and was presented at the St. Louis meeting of the American Association of Physicists in Medicine. As a result of the changes, the discrepancy with Amersham International has been resolved to our satisfaction and the calibration service resumed after a 14-month suspension. Five sources have now been calibrated using the new procedure, which also now includes mapping the source surface to very high resolution (0.2 mm) using radiochromic film read with a scanning laser densitometer. These scans are used to produce isodose-rate contour

maps which are of particular interest when the activity is not uniformly distributed on the source surface.

Radiopharmaceutical Dose Assessment (M. F. Desrosiers & B. M. Coursey)

The presently accepted dosimetry for bone-seeking radiopharmaceuticals relies on an accurate measurement of the activity administered, and calculations of the dose to the target organ (bone) as well as other organs, following the schema developed by the Medical Internal Radiation Dose (MIRD) committee. Of particular critical importance is the dose to the bone marrow, as an excessive dose may result in ablation of the bone marrow, with concurrent suppression of the immune system. We are developing a new approach to estimating the radiation dose to bone using electron paramagnetic resonance (EPR) spectrometry. Methodologies developed to assess the absorbed dose to bones of irradiated foods and radiation accident victims have been applied to bone tissues of an animal treated with a radiopharmaceutical and have demonstrated that radiation-induced EPR resonances in the mineralized tissue were measurable. Efforts are in progress to quantify the EPR spectral intensity in terms of absorbed dose. Although the EPR bone dosimetry method is invasive, it does offer the first experimental technique for measuring the tissue response to the administered radiation.

Treatment-Planning Dosimetry for Teletherapy of Intra-Oral Tumors (W. L. McLaughlin, M. Farahani, & F. C. Eichmiller)

In the radiation therapy of tumors in anatomical regions of heterogeneous tissues, the determinations of absorbed dose to cancerous as well as to healthy tissues is particularly difficult. In a collaboration with The American Dental Association Health Foundation at NIST, innovations in this film dosimetry have achieved an improved approach to treatment planning dosimetry for radiation therapy of maxillo-facial tumors. This advancement leads to more effective treatment, with improved sparing of healthy tissues by a form of custom-filled shielding. It also allows an accurate assessment of excessive radiation scattering near teeth and teeth restorations (e.g. gold crowns, silver amalgam fillings). Two archival publications in the medical physics literature have resulted from this work. New collaborative studies are proceeding on therapeutic electron beam dose distributions in heterogeneous tissues near bone, teeth, and restored teeth.

3. **Radiation Protection Dosimetry**

Currently, the efforts of NIST in radiation protection center on the measurement quality assurance programs administered by the Office of Radiation Measurement (ORM) for state, federal and private sector laboratories. The technical work in the Radiation Interactions and Dosimetry Group provides the basis for the national standards for these programs as well as the technical expertise for proficiency testing of secondary laboratories for x- and gamma-ray and beta particle instrumentation.

Standard Monoenergetic Electron Beams (C. G. Soares)

NIST has been requested by the radiation protection community to establish standards for and assist in the development of methods of measuring the beta-particle radiation fields that are found

in nuclear power installations. Beta-particle detection instrumentation is currently being calibrated using only broad-spectrum radionuclide sources at only a few fixed dose rates. In order to determine instrument response as a function of energy and rate in detail, NIST has developed a set of accelerator-produced nearly monoenergetic electron beams. A new work proposal has been submitted to the International Standards Organization to develop an international standard based on the development work done so far at NIST.

Hot-Particle Characterization Studies (C. G. Soares & B. M. Coursey)

An emerging problem in the nuclear power industry concerns the correct assessment of skin dose from contact exposure to highly radioactive microscopic ("hot") particles. Development of a technique for measuring 1-cm^2 averaged dose rate from such particles using multiple exposures of radiochromic dye films read with a scanning laser micro-densitometer continued. Collaborations with other laboratories making such measurements with different methods were initiated. The laboratories include the University of Lowell, Brookhaven National Laboratory, and Battelle Pacific Northwest Laboratory. A paper describing the NIST method was published in Radiation & Radioactivity and presented at the Anaheim meeting of the Health Physics Society.

Exposure and Dose Equivalent Response of the Panasonic Thermoluminescent Dosimeter UD802AS (M. Ehrlich & C. G. Soares)

Efforts continued to evaluate experimental data obtained by Yu Chung Yuan of Taiwan Nuclear Power Company in 1988 on energy and angular dependence of the TL dosimeter UD802AS. The corrected data were expressed in terms of "exposure response" (reading per unit exposure), for each of the NIST photon spectra and for each of the angles of radiation incidence, as well as in terms of "individual penetrating dose-equivalent response." To arrive at the latter, the individual penetrating dose equivalent, $H_p(10, \Theta)$ was, for the time being approximated by the deep directional dose equivalent, $H'(10,\Theta)$, with the aid of digitized NIST spectral data and digitized and interpolated Physikalisch-Technische Bundesanstalt (PTB) conversion factors from exposure to $H'(10, \Theta)$, where Θ is the angle of photon incidence. It is planned to utilize similar PTB conversion factors from exposure to a quantity more closely approximating $H_p(10,\Theta)$ measured on a slab phantom, as soon as these factors are available. Further analysis of the data using angle-energy algorithms developed at NIST will be necessary to develop an adequate understanding of the angular photon response of these dosimeters.

4. X-Ray Imaging Sciences

Radiation imaging remains one of the important focusses of the NIST efforts in radiation science. This is due to the tremendous importance of the use of ionizing radiation in medical and dental diagnostics and industrial applications. Recent efforts at NIST have focussed on the development of new x-ray sensors and upon evaluation of various components of the imaging chain and the physics of the interactions of ionizing radiation in matter. These pursuits are made possible due to the unique combination of available in-house radiation sources, theoretical and experimental dosimetry support, and strong interactions with university, industrial, and foreign collaborators.

Photostimulable Storage Phosphors (G. Barnea, C. E. Dick, E. Navon, A. Ginzburg, & H. Roehrig)

Experiments to evaluate the utility of a new class of x-ray imagers, photostimulable phosphors, have continued. Recent experiments have investigated the response of these materials to high energy x rays when used alone or in conjunction with metallic intensifying screens. In addition, the results of these measurements have been compared with Monte Carlo calculations. These measurements have shown that the sensitivity is proportional to the absorbed energy in the phosphor layer per cGy. In addition, the process is accurately modeled by Monte Carlo calculations which were carried out for photon energies from 100 keV to 20 MeV. These phosphors are currently under investigation for use in portal imaging, i.e. high-energy photon imaging in cancer therapy, to ensure that the treatment is specific to diseased tissue. Preliminary results indicate that the quality of the radiographs recorded is superior to those recorded using conventional techniques.

Characterization of Metallic Intensifying Screens (E. Navon, C. E. Dick, & G. Barnea)

The measurements on the sensitivity of metallic intensifying screens coupled to photographic film have been extended to 270 keV. These screens are commonly used in industrial radiography to increase the detector sensitivity and eliminate off-focus scatter. Previous measurements at 662 keV demonstrated a systematic deviation between the measurements and Monte Carlo calculations while such a comparison at 1.25 MeV demonstrated good agreement. The low-energy data indicates that the deviation between experiment and calculation increases as the energy is lowered. These data will be used to modify the Monte Carlo code for low energy photon and electron interactions. The current data also allow a good understanding of the effects of metallic screens on the relative photographic effect for energies between 0.2 and 2 MeV.

Multiple Scatter Background in Compton Scatter Imaging (G. Barnea, C. E. Dick, A. Ginzburg, E. Navon, & S. Seltzer)

Compton scatter imaging (CSI) offers an alternative method for non-invasive imaging in medicine and industry. This is particularly true in cases where the use of transmission radiography is prohibited for one reason or another. CSI may be able to provide quantitative three-dimensional information on the electron density distribution of an object. One of the largest background sources in CSI is multiple photon scattering which degrades the signal-to-noise ratio. An experiment designed to evaluate the effects of multiple scattering in low Z (aluminum) and medium Z (brass) scatterers is being implemented. The data will be compared with Monte Carlo calculations of the scattering process as a function of the scattering angle and collimator solid angle. The results will enable the design of CSI apparatus which will maximize the signal-to-noise ratio and provide optimum spatial resolution.

Coherence Effects in Cherenkov Radiation (C. Richmond & C. E. Dick)

Recent theoretical calculations indicate that Cherenkov radiation emitted as electrons pass through periodic lattices will exhibit coherence effects. An experiment to investigate this phenomenon is being designed. Electrons from the NIST 500-keV cascaded rectifier accelerator

will be used to excite Cherenkov radiation in mica targets. The resulting light will be recorded with a charge coupled device (CCD) imager and an image processing system in an effort to detect coherence effects.

Tomosynthetic Dental X-Ray System (C. E. Dick, J. H. Sparrow, & B. M. Coursey)

A five-year interagency agreement has been established with the National Institute of Dental Research/National Institutes of Health to assemble and test a small-angle tomosynthetic dental inspection system which will provide the means to quantify minute changes in dental pathologies. This program follows an NIH-funded effort at NIST in the early 80's when the technique was developed and proven using multiple static x-ray projection geometries and film. The films were digitized and manipulated by computer to generate the tomosynthetic reconstructions at the NIH facilities. The system is designed to reduce exposure to the patient while providing significantly more diagnostic information. Since this low cost x-ray inspection system will reconstruct a "slice" image at any depth determined by the operator, we believe it will have widespread industrial applications. The NIST version will be used to develop image quality standards for low energy real-time and tomographic inspections systems, study and develop techniques to acquire and retrieve radiological information normally not seen in conventional film radiography, and investigate the applicability to inspections of low-Z composite structures.

Portable 70 kV Dental X-Ray Source (J. H. Sparrow, C. E. Dick, M. R. McClelland, & B. M. Coursey)

The development of the 70-kV dental x-ray source for the Army Institute of Dental Research (USAIDR) was completed with 16 units of the 18 units assembled and delivered. Two units remain at NIST as reserves and for on-site testing. Army personnel performed rigorous environmental tests on 8 units to determine engineering changes required before fielding the x-ray source. USAIDR personnel have reported that several of these NIST portable x-ray units have been sent to the Mid-East to support operation "Desert Shield."

X-Ray Imaging Applications (C. E. Dick, J. H. Sparrow, & M. R. McClelland)

This group maintains six x-ray sources with energy ranges of from 20 to 420 kev to perform fundamental studies in development of: image quality indicators, a laser telemetering dosimetry system, measurement protocols in support of the states' quality assurance measurement programs, efficient coupling between fluorescent screens, fiber optics and imaging systems, and general nondestructive inspection techniques. These facilities are also used to support NIST's staff needs for nondestructive testing (NDT) and have been used on two occasions to radiograph candidate high-Z dental materials for casting voids.

Radiography was performed on a ceramic fuse, removed by the Norfolk, VA fire inspector, from the fire alarm-detection system of a senior citizens' home where a fatal fire occurred. The NDT radiography allowed investigators to determine the failure mode of the fuse in the warning system. This work was performed for the Fire Science and Engineering Division at NIST.

Pattern Recognition Techniques Applied to X-Ray Fluorescence Analysis (S. M. Seltzer)

In a collaboration with National Aeronautical and Space Administration (NASA) scientists, a problem was addressed concerning the selection of geological samples from the Martian surface in the planned Mars Return Sample Mission. Remote in-situ x-ray fluorescence (XRF) analysis is difficult and time-consuming, hence the desire to bring back to earth a selection of diverse samples for detailed analyses of their chemical composition. A new approach, involving the application of pattern-recognition techniques to the raw XRF spectra, was developed to distinguish and sort different samples. The method was tested on spectra from geological samples, measured with the Si spectrometer system at the US Geological Survey, and from metal-alloy and paint samples, measured with a Si spectrometer or a proportional counter using the field x-ray system developed at NASA. A PC code was developed for the rapid correlation of the raw XRF spectra, including menu-selected features such as adaptive background subtraction, specification of regions of interest, local renormalizations of intensity, variable recognition thresholds, and graphics output for both the screen and printer. Reports of this work have been prepared for the Journal of Geophysical Research, Nuclear Instruments and Methods, and Advances in X-Ray Analysis.

Tomographic Reconstruction from Multiple Pin-Hole Images (S. M. Seltzer)

In collaboration with a NASA scientist, a novel method has been devised for x-ray emission computed tomography. A constrained correlation method has been developed with which tomograms of an x-ray emitting object can be reconstructed from the detected images in a Non-Overlapping Redundant Array (NORA) multiple-pinhole system. Simple correlation (back projection) produces out-of-focus contributions in the reconstructed tomograms. Earlier methods to eliminate out-of-focus contributions (Fourier transform solutions and iterative back-projection algorithms) are computationally more difficult and lengthy. To test the new algorithm, a Monte Carlo calculation was developed to simulate the emission of rays from a collection of objects, their transmission through a multiple-pinhole mask, and their detection by a pixel array. The resultant images include the effects of counting statistics and, by an option, of background noise. The decoding of the simulated images was done for a series of objects to verify the point-spread function of the system and to determine the performance of the new method. The method has been found to be largely successful: out-of-focus contributions are eliminated in this fast, non-iterative procedure that provides a spatial resolution within well-understood limits.

C. Chemical Interactions and Dosimetry Project

1. Radiation and Oxidative Biochemistry

The goal of the program is to understand the kinetics and mechanisms of the interactions of diverse radiations and oxidative processes (single and multiple) with model and complex biosystems at the molecular level, in order to develop measurement approaches and standards for dosimetry of damage (integral and local) and repair. This fundamental understanding of molecular effects leads to diverse applications in radiation processing, molecular electronics, radiation protection, radiation biology, radiation therapy, preventive medicine, post-exposure dosimetry, and physiology.

Radiation Biomarkers (D. S. Bergtold & M. G. Simic)

The detection of radiation-induced alterations in biomolecules in vivo may be important to both the study of biological systems and the development of post-irradiation biological dosimetry for use in monitoring radiation exposure in cancer radiotherapy patients or for triage after accidental radiation exposures. Noninvasive assays of radiation biomarkers, such as hydroxy radical adducts to the DNA bases and other biomolecules, are being developed for these purposes. The most advanced technology is the measurement of urinary excretion of two nucleoside products from hydroxy radical reaction with DNA, thymidine glycol and 8-hydroxy-2'-deoxyguanosine. Current results suggest this to be a feasible approach.

Preparation of Cellular DNA for the Analysis of Damage (D. S. Bergtold, L. R. Karam, S. Sela, D. L. Bensen, L. E. Twerdok, K. D. Cole, & P. W. Todd)

Measurements of radiation damage induced in DNA in situ is a necessary prerequisite for a complete understanding of the biological effects of ionizing radiations, particularly at low to medium levels of exposure. Such measurements, however, are fraught with artifactual difficulties arising from the lack of methods to quantitatively isolate nuclear DNA from cells or tissues and the lack of generalized methods to prepare DNA for quantitative analysis of base and sugar damage without altering the quantities present in vivo. New approaches to the isolation and preparation of cellular DNA for quantitative analysis are being developed in this context.

Digestion of DNA for the Analysis of Damage Products (D. S. Bergtold & S. R. Husain)

Digestion of DNA exposed to ionizing radiation is the first step in the procedures for analyzing damage products. Two classical approaches exist: acid hydrolysis and enzymatic digestion. In neither case has the procedure been examined sufficiently for possible artifactual alterations in the quantitative yields of DNA products during preparation for analysis. In this study, parameters affecting the ability to liberate damage products quantitatively from irradiated DNA are being examined with the goal of optimizing specific procedures for specific products.

Nutrition Biomarkers (M. G. Simic, D. S. Bergtold, & L. Karam)

Biomarkers of damage and their standards are being developed for monitoring of processes in vivo. Biomarkers of oxidative DNA base damage were measured as a function of dietary caloric intake and the type of food. New methods for evaluation of foods and their components in carcinogenesis and cancer prevention are proposed. Biomarkers for noninvasive protein damage in vivo relevant to prevention of cardiovascular diseases are under development. Collaboration with the USDA Human Nutrition Lab is under development.

Mechanisms of Synergistic DNA Damage Induced by Radiation and Oxidative Agents (L. E. Twerdok & M. G. Simic)

Biological systems may be exposed to oxidants via processes such as ionizing radiation, bioactivation of chemicals or activation of the immune system. Thus, the potential for simultaneous exposure exists clinically, occupationally, and environmentally. Synergistic effects

of agents that damage biological systems via oxidative mechanisms are being investigated. Specifically, we will measure strand breaks in DNA isolated from mammalian cells damaged by single or combinations of free radical-generating agent(s) (gamma-radiation, tumor promotor(s) and activated granulocytes). Demonstration of synergistic DNA damage is expected to provide insight into biomarkers of damage, improvements in cancer therapy, and reduction in radiation-induced carcinogenesis.

Antioxidant Mechanisms and Redox Standards (S. V. Jovanovic & M. G. Simic)

Kinetics and mechanisms of potential antioxidants, i.e., inhibitors of oxidative processes, are investigated by pulse radiolysis. Energetics parameters are evaluated, redox potentials measured, and secondary redox potential standards developed. The investigations are of relevance in technology, preservation of materials, human physiology, and disease prevention (cancer, cardiovascular). The studies are done in collaboration with Max Planck (S. Steenken) and Boris Kidric (S. V. Jovanovic) Institutes.

Molecular Aspects of Ataxia Telangiectasia (L. R. Karam, P. Calsou, M. Satoh, & T. Lindahl)

Ataxia telangiectasia (a human disease characterized by an accelerated build-up of radical-induced damage and extreme sensitivity to ionizing radiation) cell lysates have been found to insufficiently metabolize deoxyribose phosphate, leading to a build-up of another sugar phosphate in the assay system. Thin layer chromatography has suggested, and gas chromatography-mass spectrometry has confirmed, that this product is glucosamine-6-phosphate. The role of glucosamine-6-phosphate in the manifestation of the disease has yet to be determined. The monitoring of this product under assay conditions has been suggested to be potentially useful in detecting the disease. A patent has been filed in both the U.S. and in Europe.

Enzyme Deficiencies (L. R. Karam, D. S. Bergtold, D. Bensen, M. G. Simic, & M. Radman)

Three DNA repair or modification enzyme deficient strains of E. coli from l'Institut Jacques Monod (Paris) are currently being used as models of radiation-induced DNA and protein damage. Through the use of the nucleic acid extractor, DNA from these strains both before and after irradiation can be easily purified for analysis of DNA modifications by gel electrophoresis and gas chromatography-mass spectrometry. In addition, modified proteins, using ortho-tyrosine and its metabolites as biomarkers, are being studied in this simplified biological model.

Hydroxy Radical Generation in Tissue - Proteins (L. R. Karam, S. Sela, & M. G. Simic)

The use of ortho-tyrosine as a marker of hydroxy radical generation in the presence of proteins has been expanded to in situ models (rat kidney). Using kidneys subjected to reperfusion damage, levels of ortho-tyrosine are measured using gas chromatography-mass spectrometry. Realizing that protein turn-over is high in living tissue, expected metabolites of ortho-tyrosine are also being monitored.

Isolation and Purification of Mitochondrial DNA (L. R. Karam, N. Noguchi, D. Bensen, & M. G. Simic)

Mitochondrial DNA damage has been suggested as a model in the study of exogenous and endogenous •OH generation, since the mitochondria are the site of cellular oxygen metabolism. Published procedures on the isolation of mitochondria have been heavily modified so as to obtain relatively clean preparations. Isolated mitochondria have been subjected to DNA extraction procedures both manually (modified plasmid extraction mini-prep procedure) and directly by the nucleic acids extractor machine. Finally, a modified extraction procedure utilizing both machine and manual techniques has yielded intact, relatively pure, mitochondrial DNA (as determined by gel electrophoresis and restriction enzyme digestion analysis). Isolated and purified mitochondria will act as models for both DNA and protein damage systems, including radiation and organic solvent-induced generation of •OH and their biomarkers.

2. **Chemical Dosimetry**

Ionizing radiation is used increasingly for industrial and materials-effects applications, and in diagnostic and therapeutic medicine, radiation safety and protection, energy development and pollution abatement. For all these applications there is urgent need for relevant measurements of radiation quantities over a wide dynamic range. Certain chemical methods of dosimetry offer significant advantages, including ruggedness, ease and repeatability of chemical analyses (e.g. spectrophotometry), the ability to miniaturize the system for high spatial resolution measurement, and the ability to change ingredients to match radiation response and energy dependence characteristics to key substances of interest (for different types of radiation). It is important to study fundamental radiation chemical mechanisms of successful chemical dosimetry systems, as well as to develop improved and novel systems with higher accuracy and precision. This includes enhancement of the ease and accuracy of analytical methods, especially since mass-produced chemical dosimetry systems are widely used for maintaining quality control and measurement quality assurance in vital applications such as treatment planning for clinical radiology, the study of radiation accidents, the sterilization of medical devices, the detection of irradiated foods, and the production and testing of a wide variety of processed goods.

Radiochromic Dosimetry Mechanisms (W. L. McLaughlin, M. Al-Sheikhly, M. F. Desrosiers, M. L. Walker, & M. Farahani)

A continuation of the study of kinetics of radiochromic dye formation in liquid solutions and in polymeric media has resulted in a new mechanistic understanding of intermediate dye radical and dye radical ion species. By the addition of certain chemical scavengers, significant

improvements in the radiation response characteristics of widely used radiochromic dosimeters has been accomplished. These include the elimination of temperature and dose rate effects, thus improving radiochromic dosimetry accuracy, as well as enhanced agreement of radiochromic response to electron and photon radiation over broad spectra of interest in industrial radiation processing. One paper describing the pulse radiolysis results has been published and two others are in preparation, one in the mechanistic understanding of radiochromism, and one on the practical improvement of radiochromic film response and its impact on routine industrial dosimetry. Within the next three years this fundamental investigation will be broadened to include other new radiochromic systems being developed at NIST and by other laboratories.

Dosimeter Film Developments and Applications (W. L. McLaughlin, C. G. Soares, M. L. Walker, J. C. Humphreys, M. Al-Sheikhly, M. Farahani, & Chen Yundong)

More sensitive versions of radiochromic dye films have been introduced. This advancement provides an exciting new tool for clinical and treatment-planning dosimetry. The newest form is a modified version of the commercially available GafChromic™ Dosimetry Media (thin-coated film), giving more accurate and precise dosimetry and high-resolution dose mapping capability at absorbed doses down to about 1 Gy. A convenient new dosimeter has also been developed for intermediate dose ranges (e.g. for food irradiation) and is being marketed by Far West Technology as a useful routine system in the dose range 10^2-10^4 Gy. Another improvement for dosimetry at very high doses (10^4-10^6 Gy) incorporates certain chemical additives in the conventional FWT-60-00 Nylon-base film, which provides a linear response function and eliminates previous uncertainties due to dose-rate dependence. All the radiochromic films that have been developed in collaborations between NIST and industry are finding increased visibility and usefulness for industrial, medical, agricultural, and materials-testing applications. A new film dosimeter service is progressing, using the scanning laser densitometer for high-resolution mapping of dose distributions in a variety of radiation beams and photon and particle fields near radionuclide sources (e.g. in anatomical tissues and phantoms). This contributes new standard methods that appear to be revolutionizing radiation measurements for clinical medicine, radiation protection, and industrial radiation processing.

Laser Telemetering Dosimetry System (M. L. Walker & W. L. McLaughlin)

Preliminary development of a laser telemetering dosimetry system has been completed for the remote, long-range detection and quantitation of gamma-ray and x-ray radiation fields. The system will allow on-line measurements in high-dose environments such as nuclear power plants and radiation processing facilities. It employs GafChromic™ Dosimetry media, a radiosensitive film that, upon exposure to ionizing radiation, visibly darkens as a function of absorbed dose, and a helium-neon laser operating at the wavelength of 632.8 nm. The film is "read" by measuring the transmitted light intensity of an incident beam and converting that quantity to optical density, thus yielding an optical density versus absorbed dose relationship. With the present film, the applicable dose range is 1 to 10^3 Gy. Configurations of the basic system allow applicability to real-time, on-line monitoring of absorbed dose and dose rate for quality control of industrial radiation processing as well as other industrial, military, and space applications.

Dosimetry for Quality Control of Low-Energy Electron Curing of Thin-Layer Materials (W. L. McLaughlin, C. G. Soares, M. L. Walker, C. E. Dick, & M. Farahani)

Low-energy electron accelerators (100-400 keV) are widely used for curing thin films, coatings, laminants, wires, cables, tubings, etc. It has recently been recognized by the radiation curing industry that thin-film dosimetry gives an important advantage, in that it provides cheap, reliable quality control of the process, as well as a useful means of validating the cure efficiency and product throughput by mapping dose distributions in thin layers and at interfaces of different materials. Work has been carried out to demonstrate the accuracy of such dose mapping by means of thin radiochromic film dosimeters, and to compare measured dose distribution profiles with the calculations of Berger and Seltzer. An invited paper on this subject was presented at the annual RadTech International Conference in 1990. Further work is proceeding on the design of thinner films for greater spatial resolution, as well as on the design of off-beam photon monitors to maintain both long- and short-term uniformity of beam parameters during the processing of fast-moving webs on the production line.

Development of Dichromate Dosimetry (W. L. McLaughlin, M. Al-Sheikhly, M. Farahani, M. F. Desrosiers, J. C. Humphreys, & Chen Yundong)

One of the most promising reference chemical systems for high doses, and in particular for transfer dosimetry serving to improve the quality control of radiation sterilization of medical products, pharmaceuticals, and prosthetic devices, is the dichromate dosimeter. Both mechanistic and practical studies of improved forms of aqueous acidic solutions of various metal-dichromic salts have significantly broadened the useful dose range of this class of dosimeters by more than an order of magnitude (now 2×10^2 to 5×10^4 Gy). These investigations have also given a basic understanding of the radiation chemical kinetics, and provide new improved values of key rate constants and radiation chemical yields, thus improving the accuracy and precision of these dosimeters. Two important findings are leading to optimal chemical means of enhancing dose rate independence of response and pre- and post-irradiation stability of dichromate dosimeters as new transfer standards for industrial radiation users of NIST Measurement Services.

Novel Radiation Sensors (W. L. McLaughlin, M. Al-Sheikhly, M. F. Desrosiers, M. Farahani, M. L. Walker, & Chen Yundong)

Several promising new chemical dosimeters have been investigated, including sugars (optical rotation measurement by polarimetry), aqueous dye solutions and vinyl films containing dyes (visible spectrophotometry), acidic aqueous solutions, zinc and calcium dichromates (UV spectrophotometry), three dimensional aqueous gels containing blue tetrazolium (visible spectrophotometry), polyolefins and cellulosic plastics (UV and FTIR spectrophotometry). Publications describing these advances are either in press or in preparation. Advantages for high-dose dosimetry include wide dynamic ranges of response, ruggedness for industrial radiation applications, and ability to measure dose distributions with high spatial resolution.

Alanine Dosimetry (W. L. McLaughlin, M. F. Desrosiers, & J. M. Puhl)

A stable free radical of the amino acid alanine is produced upon absorption of ionizing radiation. The measurement method is electron spin resonance (ESR) spectrometry. When crystalline alanine is mixed with an appropriate polymer binder, the dosimeter can be fashioned into different shapes, discs, cylinders, films. Optimization of the physical dimensions and chemical composition is in progress. Current studies are focussed on engineering aspects of alanine dosimeter manufacture.

Detection of Irradiated Food (M. F. Desrosiers & W. L. McLaughlin)

The use of ionizing radiation for the reduction of food losses and the improvement of food safety, wholesomeness and nutritional quality, is increasing rapidly worldwide. ESR spectrometry is regarded as the most sensitive and unequivocal technique for monitoring certain irradiated foods. A multinational co-trial was organized on detection and dosimetry of meats using ESR. In every instance irradiated meats were identified as such. Moreover, irradiated meats were not only identified, but relatively good estimates of the absorbed dose were obtained.

Recently, the International Atomic Energy Agency (Vienna) has organized a coordinated research program, Analytical Detection Methods for the Irradiation Treatment of Foods (ADMIT). The goal of ADMIT is to develop an array of physical, chemical, and biological tests that will enable government regulatory agencies to detect radiation-processed meats, fruits, spices, and dry foodstuffs. At the first ADMIT meeting near Warsaw, Poland, Desrosiers was selected to head the ESR special study group of ADMIT and coordinate upcoming international trials of the method.

Radiation Accident Dosimetry (M. F. Desrosiers)

A recent accidental exposure to two radiation workers in El Salvador resulted in the amputation of a leg from each victim due to radiation-induced necrosis. We have received toe, tibia, and femur bone samples from these legs. We applied ESR methodologies developed here and successfully estimated the absorbed dose level and distribution for each victim.

The project has been extended to study the radiation-induced ESR signals produced in tooth enamel, hair, nails, and articles of clothing. Promising results were obtained for certain textile fibers and tooth enamel.

Chemical Carcinogenesis (M. F. Desrosiers & D. A. Wink)

Nitrosamines have been shown to cause cancer in a wide variety of tissues. Free radical activation of these and related carcinogens are being investigated. A comparison of radiolytic versus non-radiolytic (Fenton reaction) hydroxy radical generation is being studied by ESR and kinetic techniques (pulse radiolysis and stopped flow). Major differences were noted between the Fenton and radiolytic mechanisms. Recent stopped-flow kinetic data reveal the existence of a previously postulated, but undetected, transition metal-oxo intermediate in the Fenton mechanism that mimics hydroxy radical chemistry. This is a pivotal breakthrough with extremely serious

implications for biological and biochemical researchers who currently assume that Fenton chemistry generates the hydroxy radical exclusively.

D. **Radiation Measurement Services**

Radiation measurement services provided by this project provide the physical basis for most of the Nation's quality assurance programs for ionizing radiations: medical, worker protection, industrial, and military. Combining similar services into one project provides economies of scope and scale in delivery of services to users. Innovative practices in one service are quickly adopted by others. Calibration reports, statements of uncertainties, reimbursement practices, and database management are coordinated within the project, rather than evolving separately for each type of service.

High-Energy Electron and Photon Measurement-Assurance Service (C. G. Soares)

Users of medical linear accelerators for cancer teletherapy need assurance that their machines are delivering the required radiation dosage. To meet this need, NIST offers a measurement assurance service that involves mailing to the users passive dosimeters to be irradiated in a prescribed geometry and returned to NIST for evaluation of the absorbed dose delivered. For this service, ferrous-ferric (Fricke) dosimeters are used. There were four mailings of Fricke dosimeters in FY90, involving 44 sets of participants, and a total of 154 dose interpretations. Two batches of dosimeters were prepared. In order to conserve time, and thus cost to the participants, the tests are administered simultaneously to as many participants as the batch size permits.

High-Energy Electron Beams for Radiation Processing (J. C. Humphreys, & W. L. McLaughlin)

The use of high-energy electron beams in the radiation processing industry is becoming more prevalent. These accelerator-produced beams, with energies from approximately 4 to 12 MeV, are finding increasing applications in such areas as the sterilization of medical products, the modification of polymers, food processing, and radiation-effects testing of electronic devices. Calorimeters have been constructed that will characterize and calibrate these electron beams in terms of depth-dose profiles and absolute dose. The first models of these calorimeters are arrays of graphite disks using calibrated thermistor temperature sensors. The temperature increase in each disk during a short irradiation period is measured by means of a scanned multiplexed data acquisition system. The response of passive dosimeters, such as alanine pellets or radiochromic films, may be calibrated in the electron beam by substituting those dosimeters for several of the calorimeter disks in the array. Thus, these dosimeters may be used in electron beam measurements without knowing whether their response is the same for electrons as for gamma rays. Previously, these dosimeters were calibrated with gamma rays and their response equivalency to electrons was assumed.

High-Dose Radiation Calibration Service (J. C. Humphreys, J. M. Puhl, & W. L. McLaughlin)

For FY90 the number of calibration irradiations and measurement services performed totaled 304, an increase of 14 over the previous year. These services were provided to industrial radiation processing facilities, national laboratories, universities, other government agencies, and other users at NIST. A new dose profile measurement service was initiated to provide dose mapping of both ^{60}Co sources and electron beams for customers. These mappings provide data on the best location for samples to be irradiated and the dose rate uniformity within a given volume at that location. The planning continued for a new high-activity [approximately 1850 TBq (50 kCi)] ^{60}Co irradiation facility to replace the present 37 TBq (1 kCi) source. It will have completely computerized and automated irradiations and data acquisition of all calibration parameters and should greatly improve the throughput of customer calibrations.

Profilometry of Electron Accelerator Beams (M. L. Walker, W. L. McLaughlin, J. C. Humphreys, J. M. Puhl, & C. E. Dick)

The successful mapping and characterization for two industrial concerns of their respective electron beam accelerators has been an encouraging start for the beam profilometry service. In order to map the profile of the beam from an electron accelerator, radiochromic film, of sufficient size to accommodate the entire image of the beam, is exposed to the desired electron beam. The resultant image is then digitized by a laser scanning densitometer (operating at 632.8 nm with 55-μm resolution) and redisplayed, using other in-house and vendor routines, into a optical density versus spatial location graph. These programs can present this digitized information in either isodose contour or orthographic projections, allowing easy, quantitative visualization of beam inhomogeneities or inconsistencies with high spatial resolution in two and three dimensions. A graphite calorimeter is being constructed which will allow dose calibrations to be coordinated with profilometry for electron beams.

Performance Evaluations of DoD Radiological Inspection Systems (J. H. Sparrow & M. R. McClelland)

Funded by a continuing contract with the Strategic Systems Program Office, NIST personnel provide technical support to the Navy's NDT program for inspection of large missile motors and associated components. During FY90 we performed an on-site comparison calibration between the instrumentation used to measure the x-ray energy flux density at the Navy's High Energy Computer Tomographic Facility with the NIST x-ray measurement transfer standard. For personnel protection, we measured and mapped the open-air, 10, 20, 50 μGy/hr (1, 2, 5 mrad/hr) radiation fields of the real-time high energy x-ray inspection facility located at the Navy's rocket motor static test site. Seven visits were made to Navy and/or contractor facilities to consult on radiological inspection procedures including radiation measurements, hardware inspection techniques, and the use and manufacture of image quality indicators.

X-Ray and Gamma-Ray Calibration Service (J. T. Weaver, P. J. Lamperti, & M. D. Walker)

Calibration services (x-ray and gamma-ray instruments, TLD irradiations, and electrometer tests) continue to be increasingly in demand. A total of 129 reports were issued for these tests and 8 reports on brachytherapy calibrations. Two vertical ^{60}Co sources were upgraded. A 3 TBq (80-Ci) source was replaced by a 100 TBq (2.6 kCi) source, which in turn, was replaced by a 450 TBq (12 kCi) source. The new 12 kCi source has been used for calorimetry, chemical dosimetry, and absorbed dose measurements. The air-kerma rate measurements are in progress. The air-kerma rate at a distance of 1.5 m from the 100 TBq (2.6 kCi) source has been measured using the NIST cavity chamber standards. Instrument calibrations and TLD irradiations continue, using this source. Irradiations of TLD badges and instrument calibrations for the U.S. Navy continue at about the same level as last year. The reprogramming associated with updating the x-ray data acquisition system nears completion.

III. NEUTRON INTERACTIONS AND DOSIMETRY GROUP

The Neutron Interactions and Dosimetry Group develops and applies well-characterized neutron fields and related capabilities for neutron dosimetry methods evaluation and standardization, for detector development and calibration, and for nuclear cross section measurements. Involvement with outside organizations, both in the federal and private sectors includes many types of research and technology assistance programs as well as leadership roles on national and international standards and radiation policy making bodies. A selection of accomplishments for FY-90 are outlined below in titled paragraphs grouped under four projects.

DOSIMETRY FOR MATERIAL PERFORMANCE ASSESSMENT

Dosimetry methods for monitoring the degradation of materials in high fluence neutron exposures are diverse. This project provides some form of measurement assurance, standardization, or methods development for nearly every approach to materials dosimetry employed in the United States. Interlaboratory measurement cooperation with substantial international participation are an important feature of this project.

1. NIST/NRC Contract (E. D. McGarry)

By law, Title 10 of the Code of Federal Regulations, Appendix G and H require that a program, involving irradiation of metallurgy test specimens and dosimeters, be carried out for the surveillance of pressure vessel embrittlement damage. NIST continues to participate in Pressure Vessel Surveillance Dosimetry projects connected with benchmark dosimetry measurements and calculations and in-depth dosimetry consultation.

Current dosimetry concerns have expanded to include damage in steel by neutrons in the energy range 0.01-to-1 MeV and, for different reasons, thermal and epithermal neutrons. New heavy section steel irradiation programs are underway to compare pressure vessel steel damage in spectra with enhanced neutrons in the high-epithermal ranges to in-situ damage in light-water

reactor spectra. Because these test efforts represent the design and start-up of new irradiation experiments, NIST is involved as consultant on proper dosimetry and choice of test reactors so that results from the new experiment can be compared with existing light-water reactor data. Separate concern for the very low-energy neutrons comes from experimental data in neutron spectra where the thermal-to-fast neutron ratios are a factor of 50 higher than in reactors. More damage than expected is observed at lower values of the conventional neutron fluence greater than 1 MeV.

2. Regulatory Guide Preparation (E. D. McGarry & J. A. Grundl)

NIST's involvement continues in the development of a draft regulatory guide for the NRC: "Methods and Assumptions for Determining Pressure Vessel Fluence". NIST has been a major participant in the formulation of this document which will provide guidance for improving and benchmarking neutron transport calculations. A near-final version is now being reviewed by the Nuclear Regulatory Guide for review by the nuclear industry.

The mechanism for validating calculation is comparison with accurate measurements. Discussion of neutron fluence measurement methods in the Guide emphasizes more measurements, fission neutron calibrations at NIST, quality assurance of dosimetry materials, and better reporting. There is also emphasis on validating transport calculations against experimental benchmarks and to confirm power cycle calculations against in-situ surveillance dosimetry.

3. American Society for Testing and Materials (ASTM) Benchmark Standard (E. D. McGarry)

A draft of an ASTM Standard Guide for Benchmark Referencing of Neutron Dosimetry for Reactor Pressure Vessel Surveillance was prepared by NIST and proposed for ballot at the June 1989 Meeting of ASTM E10.05. A revised draft was then sent to ASTM in January 1990 in preparation for an E10.05 ballot at ASTM and Radiation Effects Symposium meeting in Nashville.

4. NIST/Westinghouse Cooperative Agreement (E. D. McGarry)

The trend in the nuclear power industry to implement solid-state track recorder (SSTR) dosimetry in ex-vessel cavities is increasing. The bulk of the interest is in work taking place in Westinghouse pressurized-water reactors (PWRs) and in the Babcock & Wilcox Owners' Group's Davis Besse Dosimetry Benchmark Experiment. NIST is especially interested in the problem of obtaining reliable masses for SSTR fissionable deposits in the nanogram to picogram range at the Westinghouse Industrial Technology Center. The mass determinations require NIST to provide known neutron fluence exposures to ultra-lightweight SSTRs furnished by Westinghouse. The irradiations are carried out with the ^{235}U Cavity Fission Source to an accuracy of about 2.5 percent (1σ).

Cooperative research on a new dosimeter has begun. The dosimeter consists of a fissile layer placed adjacent to a polymer material that becomes conducting as a result of implantation of energetic heavy ions such as those from neutron-induced fission. The results of preliminary

calibration experiments carried out on a prototype detector in the NIST ^{235}U Cavity Fission Source were reported at the 7th ASTM/EURATOM Symposium, Strasbourg, France, August 1990.

5. Dosimetry Methods Development for Reactor Support Structures (E. D. McGarry)

A priority effort in the Heavy Section Steel Technology (HSST) Program is evaluation of low-temperature, low-fluence-rate embrittlement on reactor vessel support structures. This issue arose from findings of higher than expected embrittlement in the High Flux Isotope Reactor (HFIR) at Oak Ridge based on results from the reactor shield tank from the decommissioned Shippingport Reactor. The HFIR and Shippingport reactors have different fast fluences ($E > 1$ MeV) but HFIR has a factor of fifty more thermal fluence. The physics of interest here is that there is thought to be a thermal damage mechanism tied up with sufficient excitation energy required to displace iron atoms after the thermal capture of a neutron by any nucleus (iron or impurity atom).

Materials-damage interests in reactor support structures have not been of concern in the past because of their low exposure to fast neutrons. The emphasis now is to obtain dosimetry measurements and neutron transport calculations for the total neutron spectrum near these critical support structures. NIST is consulting and contracting for dosimetry measurements benchmarked against NIST standard neutron fields in two operating reactors. The benchmarked dosimetry will be used to adjust the calculations at the dosimeter locations prior to extrapolation of radiation (damage) exposure into the support structures.

Selected for plant-specific evaluation of support damage are the Trojan Reactor (Oregon) and the Turkey Point Reactor (Florida). Current experimental efforts focus on the Trojan plant where, under NIST advisement, dosimetry will be installed in the ex-vessel cavity. The purpose is to make measurements as close as possible to a cantilever-beam type support structure which is buried in the concrete of the biological shield. These measurements will then be used to normalize neutron transport calculations that predict cumulative exposures at critical flaw depths in the support structure. A contract for the dosimetry has been let with the Westinghouse Center for Science and Technology (formerly Westinghouse Research). A one-year-long irradiation began in late May 1990.

6. Dosimetry Development for Test Reactors Metallurgy Irradiations (E. D. McGarry & C. M. Eisenhauer)

NIST has assumed a dosimetry consultant's role for the new, combined Materials Engineering Associates (MEA)- and Oak Ridge National Laboratory (ORNL)-run HSST Program at the University of Michigan Research Reactor. The current interest in this particular reactor comes about because of the near absence of available test reactors with sufficient fluence rate (5×10^{11} n/cm^2/sec) to carry out HSST steel experiments. The ORNL Bulk Shielding Facility (a former heavily used facility) is permanently in non-operable reserve status; the ORNL Oak Ridge Research Center and the former 5MW Union Carbide Research Reactor at Tuxedo, New York, are shut down for good; and the University of Buffalo Reactor has been shut down for 18 months

for repair. The 2 MW Michigan Reactor has room for several rather large experiments and there is interest in looking at spectrum tailoring to enhance the epithermal fluence by several orders of magnitude.

7. Energy Response of Innovative Electronic-Hardware Dosimetry (E. D. McGarry & R. B. Schwartz)

The Nuclear Effects Directorate (NED) at the Aberdeen Proving Ground has been evaluating a new personnel dosimetry system for battlefield use by the Army. Special NIST neutron-field facilities were used to establish the neutron energy sensitivity of this semiconductor device. Multiple irradiations were performed in a thermal neutron beam, in the 2-keV scandium filtered beam, in the 24-keV iron filtered beam, and at the 144-keV silicon filtered beam, all at the NIST Reactor, and at several Van de Graaff beams, and finally at the NIST ^{252}Cf Fission Neutron Irradiation Facility.

8. ^{7}LiF Gamma Dosimeter for Oconee Reactor Cavity Dosimetry (D. M. Gilliam)

The results of a test of "LiF Chips" as gamma dosimeters in the cavity surrounding a reactor pressure were analyzed and reported. The results appear to contradict previously reported neutron sensitivity data and suggest that the dosimeter package may be better than expected as a gamma monitor for mixed gamma and neutron radiation fields. However, the ratio of gamma dose to neutron fluence was found to be too low in the Oconee reactor cavity for accurate gamma determination of gamma dose, until better neutron sensitivity data is obtained and until possible fading of the color center development at temperatures in the range of 50° C is ruled out.

RADIATION PROTECTION DOSIMETRY

Standard neutron fields are used to calibrate radiation protection instrumentation and to investigate and test new types of dose measuring techniques. Responsibilities in national and international dosimetry methods research focuses on tissue dose modeling, tissue-equivalent proportional counter (TEPC) measurements, and the development of written standards.

1. Instrument Calibration Service (E. Boswell & R. B. Schwartz)

Approximately 40 neutron radiation protection instruments were calibrated this year. As usual, the majority of the calibrations were done for commercial nuclear power plants, but our customers also included institutions as diverse as Redstone Arsenal and Baylor College of Medicine.

2. Alpha-Particle Spectra and Microdosimetry of Radon Daughters (R. S. Caswell & J. J. Coyne)

Due to the national problem of indoor radon, there is much interest in understanding how cancer in the lung and bronchial epithelium is produced by radon, especially radon daughters. We are studying the physics of this problem. The calculation focuses on two aspects: the alpha spectra, called slowing-down spectra, which are incident upon the cells at risk; and

microdosimetric event-size spectra which give information on radiation quality. Adapting an analytic method previously developed for neutron radiation, we have calculated the alpha particle slowing-down spectra, and subsequently the microdosimetric spectra and parameters for various airway diameters and cell nucleus or site sizes. The calculation is done in the continuous slowing-down approximation (CSDA). We have begun a collaboration with Professor Werner Hofmann of the University of Salzburg, Austria to study several biophysical cancer induction models which use these spectra as input.

3. Radiobiological Quality of Neutron Fields (J. J. Coyne & R. S. Caswell)

The biological response to neutrons varies strongly with neutron energy. One measure of this variation in radiation quality is the difference in the event-size spectra measured with TEPCs. The Caswell-Coyne code calculates these microdosimetric spectra for comparison with experimental lineal energy, y, spectra. In order to calculate y-spectra for an energy-distributed neutron source, different neutron energies must be summed in a weighted average. It has been found that these combined microdosimetric spectra can be more accurately calculated with a library of spectra generated as a function of neutron energy. A library of y-spectra for a TEPC in the ion-yield mode and for biological tissue in the energy-deposited mode are now being generated.

4. Characterization of Neutron Exposure Fields (C. M. Eisenhauer, R. B. Schwartz, J. A. Grundl, & D. M. Gilliam)

As a result of TEPC measurements, the Armed Forces Radiobiology Research Institute (AFRRI) recently obtained very surprising results in experiments which examined the relative biological efficiency (RBE) for lethality in mice exposed to reactor radiations. In brief, the experiments indicated that a slight (5 percent) addition of neutron dose, into a pure gamma-ray field, decreased the lethal dose for the mice by almost 40 percent. The neutron and gamma-ray dose components were determined by conventional AFRRI ion chamber dosimetry. However, from TEPC and fission chamber measurements made this year, it now appears that the neutron kermas measured with ionization chambers are too low. In the most extreme case the neutron kerma inferred from both TEPC and fission chamber measurements is seven to nine times greater than that measured with ionization chambers. The larger neutron doses combined with the observed lethality of mice imply a neutron RBE fairly constant with neutron energy, as expected.

5. Summary of Threshold Neutron Detector Measurements at AFRRI (C. M. Eisenhauer & J. A. Grundl)

A summary of threshold neutron detector chamber measurements made over a period of about 6 years is complete. In addition to discussion of measurements in two of AFRRI's conventional fields, the summary documents measurements with a ^{237}Np fission chamber, which is now used as a neutron monitor in AFRRI exposure rooms.

6. Microdosimetry of Low-Energy Neutrons (J. J. Coyne & R. S. Caswell)

Low-energy neutrons (below 100 keV) present a special problem in calculating microdosimetric spectra. The total kerma varies rapidly with neutron energy and dominant nuclear reactions. Also, W-values of secondary charged particles vary strongly with particle energy. The code has been modified to handle these problems. To this end, a reevaluation of W-values for secondary charged particles has been carried out. Comparisons of these calculations with measurements at the NIST reactor are underway.

7. Nanodosimetry (J. J. Coyne & R. S. Caswell)

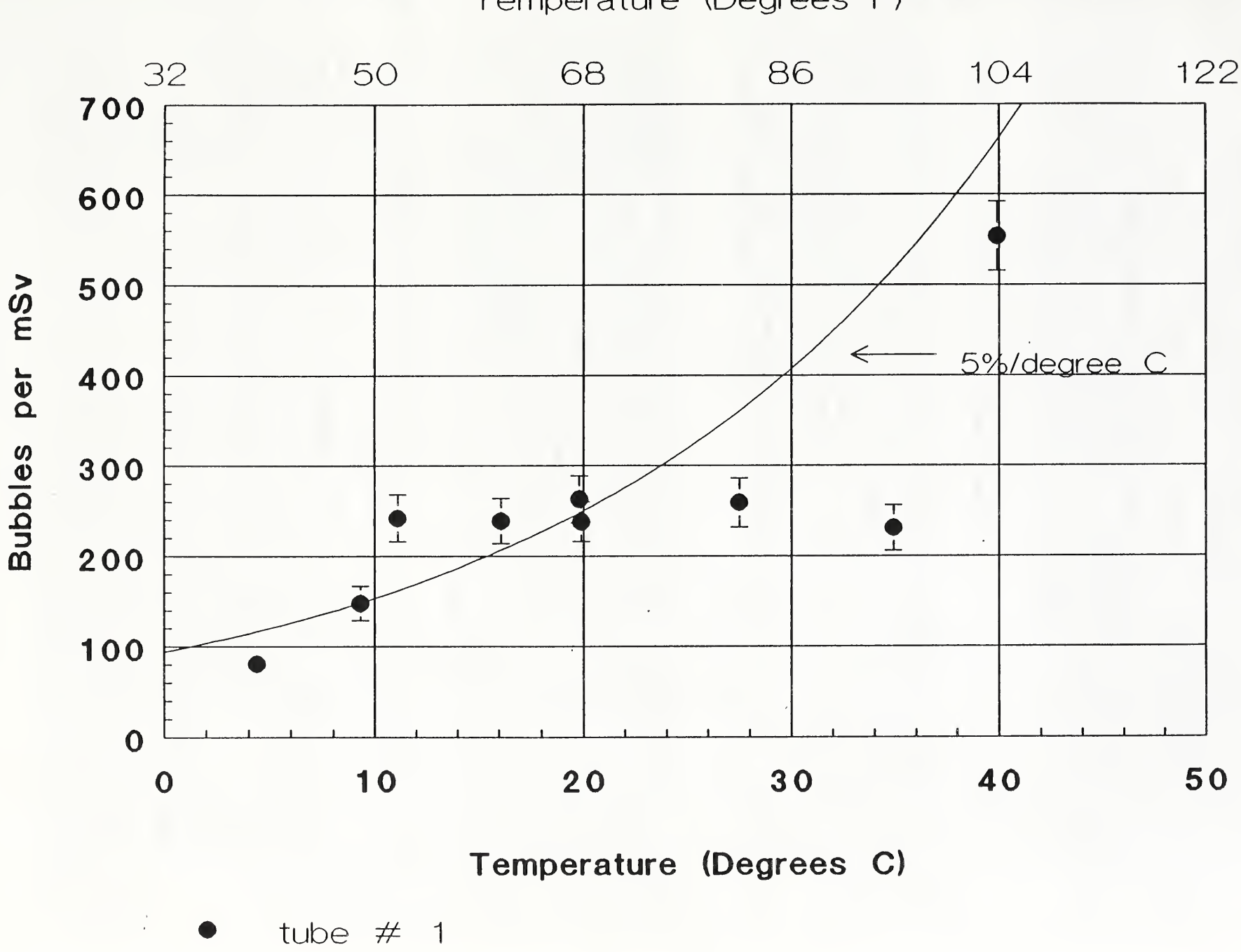
The Caswell-Coyne code has been modified to include the track-structure calculations of Wilson and Paretzke. These new calculations include the results of straggling and of energy which is lost in the cavity but is deposited outside the cavity. The effect of ions which pass by the cavity but deposit energy in the cavity are also included. Inclusion of track-structure effects allows the calculations to be extended to much smaller cavity sizes and preliminary calculations are now available down to 2 μm. Results are being prepared for publication in Radiation Research.

8. Performance Tests of "Bubble Dosimeters" (R. B. Schwartz & E. W. Boswell)

We are continuing our measurements of the properties of "bubble", or superheated drop, neutron detectors. In collaboration with J. B. Hunt of the National Physical Laboratory (NPL), we have concluded a major study of linearity, and response as a function of neutron energy, for several of these devices. Most of the data were taken at National Physical Laboratory (NPL), with additional low-energy data points taken at the NIST Reactor filtered beams. The "bubble dosimeter" (supplied by Bubble Technology, Inc. (BTI), Chalk River, Canada) has high sensitivity, a good dose equivalent response as a function of energy, and is linear up to the point where the bubbles can no longer be accurately counted. "Good . . . response . . . ", in this context, means within plus-or-minus a factor of two over the four decades of neutron energy from 2 keV to 20 MeV. The "pen" dosimeter (Apfel Enterprises, New Haven, Conn.) is easier to read than the bubble dosimeter, but has intrinsically lower sensitivity and a useful response only between ~ 150 keV and 20 MeV. The performance of the Bubble Detector Spectrometer, from BTI, was disappointing. These devices are not reliable enough to be used as intended for neutron spectrum unfolding. The results of this study are to be published in Radiation Protection Dosimetry, under the title, "Measurement of the Energy Response of Superheated Drop Neutron Detectors."

A major drawback of all devices based on nucleation of superheated drops is the rather severe dependence of sensitivity on temperature - ~ 5 percent/^{0}C. We have recently completed tests of prototype temperature compensated bubble dosimeters from BTI. While the performance of the devices was a bit erratic, they generally performed satisfactorily (within $\pm$ 10 percent) over the range from ~ 10^{0}C to 30 or 35^{0}C. The data for one of the tubes, in terms of bubbles per milliSievert as a function of temperature, are plotted on the attached figure. The error bars (one standard deviation) are based solely on the number of bubbles. In most cases, we had ~ 100 bubbles [0.4 mSv (40 mrem), from moderated californium], so the uncertainty is ~ 10 percent.

Response as Function of Temperature



(The point at 20°C was run twice: as the initial datum point, and again near the end of the test, to check reproducibility.) This test serves as a "proof of principle," and we will soon be testing the BTI production models.

We have also made preliminary tests of the Apfel Spectrometer. This device utilizes the fact that the threshold for nucleation is a function of pressure. It uses a single superheated drop detector, and a computer controlled system for stepping through a range of pressures, recording the count rate at each pressure, and then inverting the resultant data matrix to obtain the neutron spectrum. It is a very clever concept, but is not quite ready for prime time.

9. ICRU Publication on Practical Determination of Dose Equivalents (R. B. Schwartz)

As was noted in last year's progress report, the International Commission on Radiation Units and Measurements (ICRU), in ICRU Report 39, recommended a new system for determining dose equivalents resulting from exposure to external radiation sources. These new "operational quantities" have several advantages, and our report committee is preparing the ICRU report on the practical use of these quantities; i.e., instrument design, calibration techniques, etc. Our report, entitled "Measurement of Dose Equivalents from External Photon and Electron Radiations," has been completed and submitted to the main ICRU commission for its approval. (For reasons which are totally unclear, neutron radiation has been split off and will be the subject of a separate, future, document.)

The main problem for our report committee has been the choice of a phantom for dosimeter calibration; the problem arises from the statement in ICRU 39 that "... a suitable phantom is the ICRU sphere." In fact, the ICRU sphere is totally unsuitable, and much effort went into trying to determine a truly suitable phantom and calibration system which would not do violence to any of the ideas in ICRU 39. In the end, we decided to skate around the statement in ICRU 39 and recommend a simple lucite slab phantom (as is generally used anyway), together with a formulation which ties the results to the basic principles of ICRU 39. Unless this recommendation is shot down by the Commission, health physicists in the future will not have to wrestle with spherical phantoms.

10. International Standards Organization (ISO) Dosument on Instrument Calibration (R. B. Schwartz & C. M. Eisenhauer)

The (it-is-hoped) final version of ISO document CD 10647, "Procedures for Calibrating and Determining the Energy Response of Neutron Measuring Devices Used for Radiation Protection," has been submitted to the ISO secretariat, and from there gone to the member organizations (e.g., ANSI, for the US) for voting. A special meeting of the ISO working group responsible for this document is to be held at NIST during the first week in October in order to consider the comments received as part of the voting procedure. Unless serious objections are raised by member organizations, this standard should finally be on the books.

11. Data Acquisition System for AFRRI Dosimetry Group (D. M. Gilliam)

NIST has provided a PC-based data acquisition system and software to replace the two HP-85 systems previously used for Ionization Chamber and Fission Chamber data acquisition by the Armed Forces Radiobiology Research Institute Dosimetry Group. The single PC system can acquire and display data from both the ionization chambers and fission chambers either together or singly. New set-up screens replace the former sequential set-up data entry so that default selections are clearly presented and easily selected or changed.

NEUTRON INTERACTION MEASUREMENTS

Jointly sponsored by the Department of Energy and NIST, this project pursues on a long-term basis accurate measurement and evaluation of standard neutron cross sections for nuclear technology. The major experimental work including detector development is carried out at intense neutron time-of flight facilities at other laboratories, at the 100 kV ion generator and 3 MV positive -ion accelerator, and at the NIST research reactor. This project coordinates all standard cross section evaluation efforts in the U. S.

1. $^{10}B(n,\alpha\gamma)$ Cross Section Measurement from 100 keV to 3 MeV Neutron Energy (R. A. Schrack & O. A. Wasson)

Because of the large uncertainties in the value of this standard cross section in the energy region above 500 keV, a collaborative effort has been carried out with Oak Ridge National Laboratory to measure this fundamental neutron cross section. The NIST calibrated "Black Detector" neutron detector has been utilized for the measurements at the 150-meter flight path of the Oak Ridge Electron Linear Accelerator facility. This detector provided a shape determination of the neutron-fluence energy distribution in the 0.1 to 3-MeV energy region. A NIST high purity N-type germanium photon detector with 30 percent efficiency was used to measure the 478 keV photons from the $^{10}B(n,\alpha\gamma)$ process. The detector resolution was checked at NIST and then shipped to Oak Ridge where it was placed approximately 20 meters from the neutron source in the same flight path as the neutron monitor. The same ^{10}B sample used in earlier lower-energy measurements at NIST was utilized. Two months of accelerator time at Oak Ridge was dedicated to this experiment in 1990. The complex data analysis is nearing completion. Preliminary analysis indicates that the value of this nuclear data reference standard has been improved by a factor of two in the neutron energy region above 2 MeV. The cross section is in good agreement with the ENDF/B-VI evaluation in the neutron energy region below 2 MeV, but is approximately 40 percent lower at higher energies. The statistical errors in the data are better than 1 percent below 1 MeV and increase to approximately 5 percent at 4.5 MeV. An extensive investigation of the systematic errors is now underway.

2. Fission Cross Section Measurements (A. D. Carlson & O. A. Wasson)

Neutron-induced fission cross sections for actinide nuclei, important for the nuclear data program, were measured at high neutron energies where no previous data existed. The measurements, which were made on the fission flight path of the target 4 neutron facility at the Los Alamos Meson Physics Facility, cover the neutron energy region from about 1 to 400 MeV.

Fission cross section measurements are complete for ^{232}Th, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{239}Pu. The neutron fluence below 30 MeV was measured with the NIST Annular Proton Telescope (APT). Two additional detectors, overlapping in neutron energy ranges, allowed data to be obtained from about 2 MeV to above a hundred MeV. The Low Energy Telescope (LET), which used a thin polyethylene film and Si(Li) detector in a vacuum enclosure at 15 degrees from the neutron beam line, supplemented the APT measurements for neutron energies below 30-MeV. Higher neutron energies were detected by the Medium Energy Telescope (MET), which was placed at an angle of 15 degrees from the beam and in air downstream from the LET. The MET, composed of a polyethylene disk and three proton recoil scintillator detectors, was used in a coincidence mode in order to reduce the neutron background. The use of the new MICROVAX-XSTS computer-data acquisition system at LANL has significantly improved the data accumulation process. The options for monitoring the quality of the data are significantly better than were available previously.

The main effort during the past year was directed towards an improved understanding of backgrounds. Mass determinations for the fission deposits used in these experiments were obtained from low geometry alpha counting. The fission ratio and cross section analyses are nearly complete and work has begun on publication.

3. Remote Data Acquisition from Oak Ridge National Laboratory (R. A. Schrack)

The transmission to NIST of experimental data acquired under remote operating conditions at Oak Ridge National Laboratory has undergone rapid improvement in the past year. The acquisition of a compression program has allowed ASCII programs to be reduced in size by about a factor of ten. It has also become feasible to transmit binary files directly to our local microcomputers. We have installed an ethernet local area network at NIST that allows direct transmission without the need for a local host computer. Transmission of the experimental data that took several hours last year can now be accomplished in about thirty seconds. While data transmission problems have been effectively solved, we are looking into the possibility of real time remote monitoring of experiments that would allow the detection of experimental difficulties in a timely manner.

4. Remote Data Acquisition and Analysis at the LANL WNR Facility from NIST (A. D. Carlson)

Performing experiments in the 'host' mode can be difficult since the experimenters often are not able to remain at the host site for the duration of the experiment, particularly for low count rate experiments. For the NIST-LANL collaboration, a system has been set up which allows a remote connection to the WNR MICROVAX computer with a modem. Thus it is possible, from NIST, to use regular telephone lines and a personal computer with a terminal emulation program to inspect the experimental data being accumulated at LANL. The remote user has essentially the same options as the local user. For example, one can view pulse height and time-of-flight distributions, stop and start data accumulation runs, clear data arrays, write data analysis programs, etc. Any problems or concerns about the data being acquired can be communicated to LANL collaborators who will investigate the difficulty. This method of using the LANL computers has been improved recently with the use of special high speed communication lines.

Noise, which has often caused broken modem connections on regular telephone lines, has not been a problem on these lines. These improved lines can provide rates as high as four times what was possible previously.

5. The Evaluation of the Standards for ENDF/B-VI (A. D. Carlson)

The ENDF/B-VI evaluation of standard neutron cross sections is complete and accepted for use in ENDF/B-VI by the Cross Section Evaluation Working Group (CSEWG). Concern in the phase I review of these standards about rather small values of some uncertainties, resulted in expanded uncertainties for the ENDF file.

The covariance files for the combined output are available but are very large (about half a million elements). The number of experimental data points is only about ten thousand so it is clear that the covariance matrix is larger than necessary. The matrix will be collapsed keeping most of the covariance elements located near the diagonal and those in the regions where the covariance elements are changing most rapidly. Possible expansion of the uncertainties due to smoothing of the cross sections or new information available since the evaluation will be considered.

6. Multielemental Assay of Bulk Material Using 2.5 MeV Neutrons (K. C. Duvall & O. A. Wasson

A new method for obtaining information on the elemental content of bulk material has been implemented. The technique employs the time-correlated associated particle (TCAP) method to produce a neutron probe with well-defined time characteristics. Good timing is used to separate the prompt inelastic scattered gamma-rays from the more complicated delayed spectral components. Unlike recent measurements reported in the literature that use the 14 MeV neutrons, our measurements on bulk samples were carried out with a 2.5 MeV probe that does not produce high energy gamma ray lines from carbon and oxygen which can impair the assessment of some elemental constituents. The feasibility of using this technique for biomedical measurements of the magnesium content of the human body is being studied.

7. International Fast Neutron Fluence Intercomparison using Fission Chamber Transfer Instruments (A. D. Carlson, R. A. Schrack, & R. B. Johnson)

NIST and six other international standards laboratories participated in an intercomparison of accelerator-based fast neutron fluence measurement capabilities. The intercomparison was organized by the BIPM in conjunction with the Harwell Laboratory which provided fission chambers and coordinated the measurements and analysis. NIST was the only laboratory to use both linac-based white neutron spectra and monoenergetic neutrons produced by the 3-MeV positive-ion accelerator. Measurements were completed in 1985 at a neutron energy of 0.55 MeV for both facilities. The results of the intercomparison were recently submitted for publication in Metrologia.

RESEARCH AND TECHNOLOGY

Research and technology assistance are strongly coupled in neutron dosimetry. A multiplicity of institutional involvements, drawn to the group by the availability of unique irradiation facilities and measurement capabilities, encourages a variety of attractive projects.

1. Neutron Lifetime - Absolute Neutron Counting (D. M. Gilliam)

The result of the first phase of the Univ. of Sussex/NIST/Geel collaboration to measure the free neutron lifetime was reported in Phys. Rev. Letters. The goal for this first phase of the project was to achieve an overall uncertainty of $\pm 0.5\%$ at this juncture; and the reported value of 893.6 ± 5.3s comes very close to this goal.

Two additional papers were presented documenting the work of the Central Bureau for Nuclear Measurements (Geel, Belgium), Univ. of Sussex, and NIST to make characterized deposits of B-10 and Li-6. These papers were presented at the International Nuclear Target Development Society meeting in Santa Fe (9/90) and will be published in a special issue of Nucl. Inst. Meth. in Phys. Res.

The NIST alpha-gamma coincidence apparatus has been tested with an isotopic alpha-gamma source and is ready for neutron beam runs as soon as a beam is available. This device is meant to achieve absolute neutron counting by means of the alpha-gamma coincidence method without reference to isotopic target mass assay. Nevertheless, a continued collaboration with Geel in further refinement of B-10 deposits is planned, as well as continued collaboration with Harvard Univ. and Los Alamos National Laboratory in calorimetric neutron counting.

2. Benchmark Measurements for Criticality Safety Calculations (D. M. Gilliam & J. A. Grundl)

In collaboration with Los Alamos National Laboratory and Oak Ridge National Laboratory, an experimental program has been undertaken to improve the understanding of neutron leakage from aqueous systems which are representative of situations occurring in chemical processing of isotopes for nuclear weapons production. There has been a long-standing difficulty in the field of criticality safety of calculating criticality of systems composed of multiple sub-critical assemblies. One possible explanation for the difficulty is that the calculations are incorrectly predicting the neutron leakage from the individual assemblies. The present program compares calculations by two of the best Monte Carlo codes with state-of-the-art measurements for spherical aqueous systems driven by ^{252}Cf neutron sources. Fission ionization chambers with fissionable deposits from the NIST collection of Fissionable Isotope Mass Standards (FIMS) are employed to make the neutron leakage measurements.

Two series of careful measurements of neutron leakage from a water-moderated ^{252}Cf source have been completed and compared with rigorous Monte Carlo calculations performed by the Computational Methods Development Group at Los Alamos Scientific Laboratory. The first results from this program were for the case of a 10 cm (4 inch) diameter sphere of water. For this case very detailed calculations by the MCNP code required about fifty hours of super

computer time. The comparisons of measured and calculated fission rates outside the sphere showed some interesting discrepancies. The thermalization was overpredicted in the calculations relative to the measurements. A number of auxiliary tests for unexpected absorption of thermal neutrons in the water, steel spherical shell, or fission chamber components failed to reveal any contamination that could explain the discrepancies. These results will be reported in the American Nuclear Society Transactions, Winter, 1990. A second series of measurements with a 7.5 cm (3 inch) diameter sphere appear to show the same discrepancy in thermalization. The discrepancies for ^{235}U and ^{239}Pu fission rates are of the order of 4 percent to 7 percent, well beyond the combination of the overall uncertainty of the experiment and the statistical error of the calculation. However, the known errors in the cross section data and the thermalization model employed may be sufficient to explain the discrepancies. A complete uncertainty analysis is not yet available for the calculation, including the uncertainties of the cross sections and the $S(\alpha,\beta)$ thermalization model.

3. Neutron Fluence Rate Measurements at the NIST Cold Neutron Research Facility (CNRF) (D. M. Gilliam)

Several measurements of both fast and thermal neutron fluence rates were made at various positions on cold neutron guide NG6. All of these measurements were made at a time when the cold source was not operational and filled with warm helium gas rather than heavy water ice.

On April 8, 1990, when NG6 had been built only a few feet beyond the wall of the reactor building, a series of thermal and fast fluence rate measurements were made at the end of the guide as it stood at that date. These measurements were made at reactor power levels of 20 kW, 50 kW, 200 kW, 500 kW, and 1 MW. Since the average thermal neutron speed was not known, the thermal neutron results were reported as if the neutron speed were 2200 m/s. The fluence rate derived in this way is also known as the "capture flux." The energy spectrum of the fast neutrons was also unknown, and the fast neutron data was interpreted as if the fast spectrum were an unmoderated fission spectrum from the thermal neutron fission of ^{235}U. The fluence rate determined in this way is termed the "fission-equivalent fluence rate." The guide was evacuated during these measurements.

On May 8, 1990, with the guide built to full length, the fast and thermal fluence rate measurements were repeated at 1 MW at the end of the guide. The guide was filled with helium somewhat contaminated with air. On May 17, 1990, the thermal fluence rate measurements were made once more with the guide filled with pure helium. These measurements were made at two positions: at the end of the guide, and inside the guide at an access point about 3 meters outside the reactor building wall.

4. Collaboration with U. S. Naval Academy (C. M. Eisenhauer)

Monte Carlo calculations with the MCNP code at NIST have been used to determine the neutron spectrum from a 14-MeV neutron generator at the U. S. Naval Academy (USNA). Comparisons of dose equivalent with similar calculations by USNA showed a significant (40 percent) discrepancy. Further investigations revealed that the MCNP code at USNA did not duplicate sample problems distributed with the computer code package. It is not clear whether

the discrepant values are due to the particular version of the code used at USNA or due to adaptation to their computer.

5. **Collaboration with Institut de Protection et de Sûreté Nucléaire (IPSN)** (C. M. Eisenhauer)

Because of our experience in calculations of anisotropic emission from small neutron sources, NIST was asked to make calculations for a source used by IPSN. We also checked their calculations of neutron spectra from a 14-MeV neutron source moderated by iron, ^{238}U, and heavy water. This collaboration arose out of participation on ISO committee TC85, subcommittee 2, "Radiation Protection."

6. **Neutron Penetration in Slabs of Finite Extent** (C. M. Eisenhauer)

Monte Carlo calculations of neutron transmission through slabs have been performed to help the U.S. Navy estimate shielding of personnel on submarines carrying nuclear missiles. These calculations demonstrate that neutron and gamma-ray penetration is insensitive to the position of a slab between a localized (point) source and detector. Furthermore, an angular parameter can be specified such that the relative contribution of neutrons or photons within that angle is also insensitive to the slab position. This is equivalent to quantifying the increase in scattered particles as one moves from a narrow-beam to a broad-beam configuration. A paper on the subject has been accepted for publication in Nuclear Science and Engineering. An oral paper has also been accepted for delivery at the Winter Meeting of the American Nuclear Society.

7. **Radiation Shielding Calculations for the NIST Cold Neutron Facility (CNRF)** (C. M. Eisenhauer)

Calculations of the necessary shielding for two shutters at the CNRF and for shielding around neutron guides were made. The latter calculations approximated the neutrons scattered from the walls of a guide as a line source. All calculations predicted dose equivalent rates which were conservative as determined by measurements with shielding in place.

8. **Staff Member Elected to NCRP**. C. Eisenhauer was elected to the National Council on Radiation Protection and Measurements.

IRRADIATION AND CALIBRATION FACILITIES

Well-characterized neutron fields, built and maintained as permanent irradiation facilities, provide certified fluences of pure fission neutrons, sub-MeV distributions, monoenergetic keV beams, and thermal neutrons. Passive and active detectors are exposed in these neutron fields for response calibrations, for cross section measurements, and for the investigation of new measurement techniques. A multi-purpose fission rate measurement capability is centered around the NIST "go anywhere" double fission chambers and the NIST set of fissionable isotope mass standards (FIMS). The Manganous Sulfate Bath is the primary neutron source strength calibration facility for the U. S. Absolute neutron fluences for all fission-neutron-driven standard neutron fields at NIST are derived from source strength calibrations at this facility.

1. Neutron Source Strength Calibrations in FY-90 (E. D. McGarry & E. W. Boswell)

Fifteen neutron source-strength calibrations were accomplished this year at the $MnSO_4$ Bath Facility. Eight of the calibrations were accomplished under Standards Publications (SP-250) contracts for customers identified in Table 1. The remaining calibrations were for in-house neutron sources used at the ^{252}Cf Fission-Neutron Irradiation Facilities.

TABLE 1. Customers for FY-90 Neutron Source Emission Rate Calibrations

Laboratory/Company	No. of Sources	Type of Source
Oak Ridge National Laboratory	2	^{252}Cf
Battelle Pacific Northwest Laboratory	1	^{252}Cf
Sandia Laboratory	2	^{238}Pu-Be
NAVALEX Laboratory, Charleston SC	1	^{239}Pu-Be
Naval Research Laboratory	1	Am-Be
Brookhaven National Laboratory	1	^{252}Cf

There was an on-site refurbishment of the slave manipulator arm by Sergeant Industries. This included some hands-on maintenance training of NIST personnel.

2. New Reference Neutron Field to Support NIST/NRC Dosimetry Contract Work (J. A. Grundl & E. D. McGarry)

To supplement calibration and benchmarking irradiations carried out in NIST standard fission neutron irradiation facilities, there is a need for a higher fluence rate and larger volume irradiation facility to accept dosimeters integrated into steel capsules. The University of Michigan Reactor has expressed an interest in cooperative development of such a facility at their 2MW swimming pool reactor.

3. Fission Neutron Irradiations Operations (E. W. Boswell & J. A. Grundl)

The storage cave for radioactive sources and standard neutron field assembly pieces is essentially complete. The extensive heavy-work required to build this facility was carried out entirely with staff personnel.

IV. Radioactivity Group

Although each year brings new challenges that affect the balance of techniques development, radionuclide standardization, testing programs, standard reference material (SRM) production and calibrations services, the measurement of emission probabilities and half lives, international interactions, and education activities in the Group, the constant driving force is the concept that radioactivity measurements in the U.S. should be demonstrated as being traceable to the national standards of the radionuclides involved. This has brought long-term programs with regulatory agencies (EPA, FDA, and NRC), and industrial groups (nuclear medicine and electrical power)

under the umbrella of the U.S. Council for Energy Awareness (USCEA). Programs for environmental and biological monitoring, in cooperation with the Office of Radiation Measurements, may supplement considerable radon measurement efforts in re-energizing our low-level-radioactivity involvement. And since the basis for all this is the ability of the Group to measure, the maintenance, improvement, and understanding of equipment and techniques must have high priority. Several of these aspects are addressed in the sampling of FY 90 activities which follow.

Review of the USCEA/NIST Measurement Assurance Program for the Nuclear Power Industry (D. H. Gray (USCEA), D. B. Golas (USCEA), & J. M. Calhoun)

An article with the above title and authors has been prepared to summarize the data collected in the first three years of this cooperative program to test radioactivity measurement traceability in the nuclear-electric-power industry. Two Research Associates from the USCEA work with the Radioactivity Group to develop test samples pertinent to the industry, and distribute six of these each year with activities unrevealed until the participant's value is reported.

The participating companies, 12 in number originally and 19 at present, include not only utility radiochemistry laboratories and contract service laboratories offering measuring and testing services, but also commercial suppliers of calibration materials. The latter not only receive any appropriate test samples, but also submit up to 14 of their certified sources or solutions annually to demonstrate measurement traceability to the national standards.

Through April 1990, 363 "blind" test samples had been distributed, involving 590 activity measurements. The distribution of results received is shown in Figure 1. The means of the ratios to the NIST value and estimated standard deviations were 0.993 ± 0.087 for the utilities, and 1.000 ± 0.069 for the source suppliers and service lab. The corresponding values for sources submitted by the latter to NIST for traceability testing were 1.0019 ± 0.019.

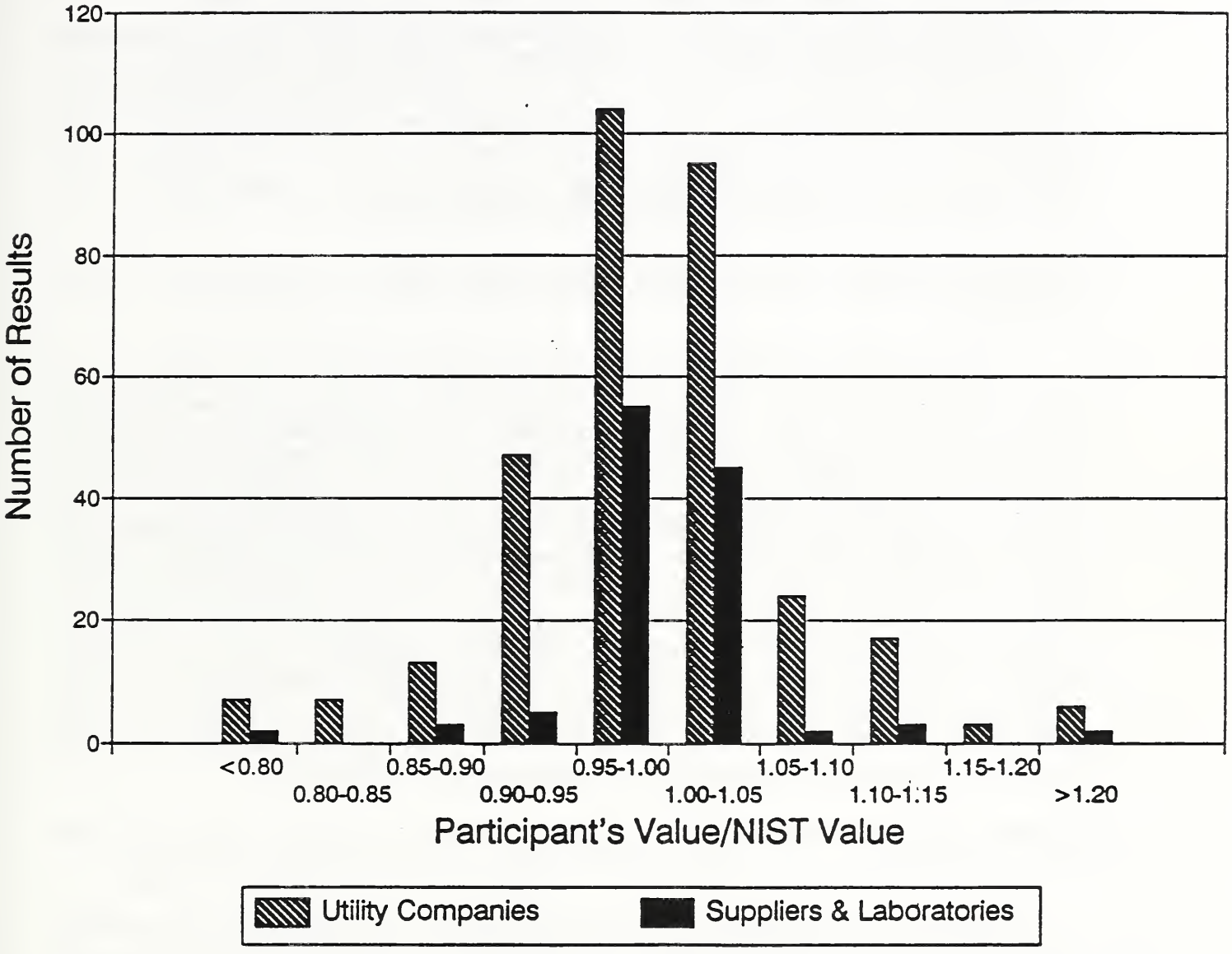
The program has involved at least 41 of the 109 commercial nuclear generating plants in the U.S., and has in general demonstrated a satisfactory measurement ability. In cases where significantly discrepant results were reported, the participant was assisted in making corrections.

Department of Defense Interactions (J. M. R. Hutchinson, M. P. Unterweger, J. Cessna, & P. A. Hodge)

A defined geometry NaI(T1) counting system for the measurements of plutonium L-x-rays emitted from large-area sources has been designed, constructed, and calibrated. The sources used were 20 cm x 12.5 cm (8-in x 5-in), 7.5 cm (3-in) diameter, and "point" sources - all of ^{238}Pu. The sources were also calibrated by alpha-particle counting in the NIST large-area proportional counter. Using a value of the x/γ ratio from the literature, the results were intercompared, with a discrepancy of approximately 7 percent between the two sets of measurements. The difference will be investigated in the coming year.

Eight commercial radioactivity surface-monitoring systems were compared for sensitivity, selectivity, energy-discrimination level, and variability of response across the probe faces. Large differences were found from probe-to-probe. The data will be used by the U.S. Navy to select

Figure 1.


120
100
80
60
40
20
0
Number of Results
<0.80
0.80-0.85
0.85-0.90
0.90-0.95
0.95-1.00
1.00-1.05
1.05-1.10
1.10-1.15
1.15-1.20
>1.20
Participant's Value/NIST Value
Utility Companies
Suppliers & Laboratories

the next generation of such probes, which are mainly designed for use in nuclear accidents or in battlefield situations.

^{222}Rn Measurement Intercomparisons (J. M. R. Hutchinson, J. Cessna, R. Collé, & P. A. Hodge)

NIST has completed one measurement intercomparison this year with four international laboratories and initiated a second with six additional laboratories. One of the main objectives of these intercomparisons was to attempt to resolve disturbing 7-11 percent discrepancies between major quality control laboratories. The intercomparisons were performed with specially designed and tested spherical bulbs, the radioactive contents of which can be accurately assayed in a well NaI(Tl) detector. The results so far show both consistencies and inconsistencies with previous intercomparisons which have been performed over 10 years or more.

Collaborative Studies with the Radon Measurement Industry (R. Collé, & J. M. R. Hutchinson)

Collaborations with three principal radon instrument manufacturers and measurement vendors have been initiated in order to develop more directly useful transfer standards and calibration protocols for the entire radon measurement industry. The collaborations involve developing procedures and testing the newly developed ^{226}Ra capsule prototypes in different configurations and measurement applications. Considerable work has been done on demonstrating the use of the capsules for calibrating integral passive radon monitors (electrets) in static accumulation environments. This work is being done in collaboration with Rad Elec., Inc., one of the major instrument manufacturers. The second collaborative study is with UNC-Geotech (Grand Junction, CO), a DoE prime contractor laboratory that maintains an independent radon calibration capability based on ^{226}Ra solution standards. In this study, the capsules are used in a "bubbler" accumulation configuration similar to that used by both them and by our laboratory with solution standards. The third collaboration is with Radonics (Baltimore, MD), a major nation-wide firm that provides radon measurement and remedial action services, in which the capsules are used in continuous flow-through measurements over long time periods (many months).

Standard Reference Materials (J. M. Calhoun, J. T. Cessna, D. Golas, D. Gray, K. G. W. Inn, & L. L. Lucas)

The Radioactivity Group disseminates standards that provide measurement quality assurance to the nuclear medicine industry, nuclear-power industry, environmental monitors, producers of radionuclides, manufacturers of instrumentation important for the measurement of radioactivity, and commercial suppliers of calibration materials. Most of the Radioactivity SRMs, other than those issued for nuclear medicine are long-lived radionuclides which will serve as useful standards for many years. During the past year, certifications have been completed for several radionuclides, ^{242}Pu, ^{243}Am, ^{137}Cs, ^{10}Be, and ^{14}C.

- ^{242}Pu is used as a tracer in the assay of ^{239}Pu. NIST has provided ^{242}Pu high purity SRMs, but recently the SRM material has been unavailable. The users of this important standard have been very patient in waiting on its production, and these standards will soon be disseminated.

- ^{243}Am, an alpha-particle emitter used as a chemical-yield monitor in the radiochemical analysis of ^{241}Am has been certified and reissued. This SRM is important for the investigation of americium concentrations in the environment of nuclear-fuel-cycle and nuclear-weapons facilities.
- ^{137}Cs is required in nuclear-power-plant facilities for monitoring the status of fuel rods.

- ^{10}Be-^{9}Be is an isotopic-ratio standard meeting an expressed need in the geochronology field. These standards were issued for the first time as prototype standards.

- ^{14}C-hexadecane is important as a reference standard in liquid-scintillation counting. The standards have been prepared and the certification process is being completed.

The following table enumerates some interactions with the public in FY 90:

Total radioactivity SRMs distributed	727
Short-lived SRMs supplied under the USCEA program for nuclear medicine	227
Scheduled calibrations	22
Special measurements	15
Traceability tests for EPA, FDA, NRC, and commercial firms	213

Production of Ultra-pure ^{242}Pu Special Sources and SRMs (J. M. Calhoun, D. Golas, D. Gray, K. G. W. Inn, & L. L. Lucas)

There is currently a severe shortage of ^{242}Pu of sufficient radiochemical purity to be used as a tracer in radiochemical analysis, including environmental and personnel monitoring. Such environmental and personnel monitoring is required by law for nuclear installations to remain in operation. The Lawrence Livermore National Laboratory (LLNL) of the U.S. Department of Energy (DoE) has now mass separated and chemically purified several milligrams of ultra-pure ^{242}Pu. LLNL may be able to produce several additional milligrams in the near future.

In the past, the Isotope Sales Division at the Oak Ridge National Laboratory of the DoE has handled the sale and distribution of such materials. Due to a change in DoE policy, this is no longer possible. After extensive negotiation, DoE, LLNL, and NIST have agreed on a price and

method of distribution for this material. NIST will now handle the sale and distribution of this ultra-pure ^{242}Pu in the form of special sources (either with or without a NIST Report of Test) at higher activity levels and in the form of SRM 4334D at a lower activity level (approximately 25 Bq g^{-1}).

The ^{242}Pu special sources and SRM 4334D are expected to be available from NIST early in FY 91. U. S. Government facilities will have first priority for the special sources. It appears that enough material will be available to satisfy the shortage that has developed during the past few years and to provide adequate standards for several years to come.

Development of Polyethylene-Encapsulated ^{226}Ra SRMs (R. Collé & J. M. R. Hutchinson)

In the past year, considerable progress has been made in developing a prototype polyethylene-encapsulated radium solution standard that may serve as an alternative transfer standard for several different types of radon measurement calibrations. This work received development funding from OSRM. The encapsulation technique, which appears to be very successful, is similar to that originally developed by NIST for trace-gas "permeation" tube calibration standards. The feasibility and efficacy of the prototypes for use as radon-measurement transfer standards has been clearly demonstrated. The prototypes have been extensively tested by several measurement methods in a wide range of activity concentrations under different accumulation conditions. The most extensive set of measurements have been made by liquid scintillation (LS) counting of the capsules directly in the LS cocktails. Although it was originally envisaged that these LS measurements would mainly be used to test and evaluate the capsules, it now appears that the capsules may also be suitable as a direct transfer standard for calibrating radon-in-water LS measurements.

Primary ^{222}Rn Measurement System (J. M. R. Hutchinson, R. Collé, M. P. Unterweger, & P. A. Hodge)

The new ionization chambers were recalibrated. Some modifications to the gas handling and gas purification manifold were found to be necessary and were made. After this, the calibration data showed precisions that were accounted for by counting statistics alone, with essentially no gas-transfer or gas-handling uncertainties manifested. The chambers were calibrated against radium solution standards in modified gas washing bottles as well as being used to evaluate the new prototype polyethylene-encapsulated radium standards and to calibrate the NaI(T1)-based secondary measurement system which is used for interlaboratory intercomparisons.

Consistency of ^{226}Ra and ^{222}Rn Calibrations by Liquid Scintillation Counting (R. Collé & J. M. R. Hutchinson)

Efforts are underway to reconcile and evaluate the consistency between ^{226}Ra and several ^{222}Rn calibrations based on LS counting. This is being done to insure the necessary linkage and compatibility of several kinds of measurements and calibrations used in the overall NIST radon standards program. Comparisons between the following are being performed: direct measurement of calibrated ^{226}Ra solutions by LS counting; direct measurement of the ^{226}Ra prototype capsules by LS counting; and LS measurements of water samples obtained from the radon-in-water

standard generator (which employs the capsule as the generating source). Confirmatory measurements of all of these elements by pulse-ionization counting with the primary measurement system are also being made.

Solution Stability of Polonium SRMs (R. Collé)

A project to evaluate the long-term stability of polonium solutions has been initiated. It was believed that tests on the stability of existing ^{208}Po solution standards (SRM 4327 issued in 1985) should be done prior to preparing and issuing the planned new ^{209}Po solution SRMs. The evaluations are being made by LS counting. In addition to testing the 1985 SRMs which were put up in 1 N HCl, several older calibrated ^{208}Po solutions (1982) in both 0.3 and 1.5 N HCl are being evaluated.

Radionuclide Standard Development: ^{58}Co (A. T. Hirshfeld (contractor) and D. D. Hoppes)

Test samples of ^{58}Co of known activity were required for a USCEA program, but no well-documented standardization had been performed at NIST. The NIST (4π pressurized proportional counter)(NaI(T1)) anticoincidence system was used, with efficiency extrapolation, to perform such a basic standardization, and the result was transferred to reference ionization chamber A for future use. Component uncertainties, estimated as standard deviations and combined as if statistical quantities, totaled 0.4 percent. Corrections for a ^{57}Co impurity ranged from 0.47 to 0.63 percent during the weeks the thin-film sources were measured.

Radionuclide Standard Development: ^{123m}Te (B. M. Coursey, D. B. Golas (USCEA), D. H. Gray (USCEA), D. D. Hoppes, & F. J. Schima)

Some of the commercial reference-source suppliers who had assumed distribution of mixed-radionuclide spectrometer-calibration sources developed at NIST substituted ^{123m}Te for ^{139}Ce when the latter became difficult to obtain. The 159-keV gamma-ray probability per decay (P_γ(159)) appears in evaluations as 0.840 ± 0.004, which allows the ^{123m}Te to be used for a "primary" efficiency-calibrated point if the activity can be measured accurately.

That proved to be relatively simple, for the 88-keV transition preceding that of 159 keV produces conversion electrons with energies greater than 50-keV energy 99.96 percent of the time. These are counted with almost 100 percent efficiency in a commercial liquid-scintillation counter, and the resulting spectrum provides interesting checks of decay parameters and detection processes. Impurities of ^{121}Te, ^{121m}Te, and ^{110m}Ag totaled 0.67 percent. The combined uncertainty of the activity measurement is estimated as 0.5 percent.

A direct measurement of P_γ(159) with activity-calibrated sources and a calibrated germanium spectrometry system gave a value of 0.842 ± 0.006, compatible with the use of ^{123m}Te as a "primary" radionuclide. Half-life measurements with the spectrometry system gave a preliminary value of 119.2 ± 0.1 days.

Radionuclide Standardization: ^{188}Re J. M. Calhoun, J. Cessna, B. M. Coursey, D. B. Golas (USCEA), D. D. Hoppes, F. J. Schima, & M. P. Unterweger)

The radionuclide ^{188}Re has several advantages as a new therapeutic high-energy beta-particle emitter in nuclear medicine: its energy and half life are suitable; a 155-keV gamma-ray provides self-imaging to show that it has gone to the targeted organ; attachment to specific agents is understood; and it can be produced essentially free of troubling impurities from a ^{188}W generator that is not costly to prepare. In a collaboration with Oak Ridge National Laboratory, material produced from such a generator has been used to develop a national standard of ^{188}Re and measure pertinent decay parameters.

Liquid-scintillation counting with calculated efficiency tracing with ^{3}H was used to measure the activity to an estimated combined uncertainty of 0.3 percent. Quantitatively related point sources were used with calibrated germanium spectrometers to measure a $P_{\gamma}(155)$ of 0.1588, with a combined uncertainty of 0.7 percent, and give improved emission probabilities for x-rays and weaker gamma-rays.

Ampoules of two different batches were measured in NIST reference ionization chamber A for about seven half lives. Impurities of ^{188}W, ^{134}Cs, ^{192}Ir, and ^{110m}Ag totalling less that 0.002 percent initially were detected by gamma-ray spectrometry. When the data were corrected for these, a resulting ^{188}Re half life of 17.01 $\pm$ 0.01 hours was obtained.

Provisional Use of Hungarian Radioactivity Standards (J. M. Calhoun & D. D. Hoppes)

The NIST Radioactivity Group is temporarily adopting certain Hungarian radioactivity standards where no well documented U. S. standard yet exists. The National Office of Measures in Budapest has determined by direct methods the activities of several radionuclides which are of interest to the nuclear-electric-power program. Standards developed at OMH were obtained for ^{65}Zn, ^{86}Rb, ^{192}Ir and ^{106}Ru. As a check, ^{141}Ce and ^{144}Ce-^{144}Pr, recently standardized at NIST, were compared with corresponding OMH standards; the respective differences were +0.89 and +1.02 percent.

A working visit was made by Jacqueline Calhoun as part of the NIST/OMH cooperative program. The observation at OMH gave NIST a better understanding of the Hungarian techniques in source preparation and absolute and relative activity measurements.

New and Revised Half-Life Measurement Results (M. P. Unterweger, D. D. Hoppes, & F. J. Schima)

The half lives of many radionuclides have been measured in the Radioactivity Group over the last three decades. The results of these measurements for long-lived radionuclides, such as ^{60}Co, ^{137}Cs, ^{85}Kr, ^{22}Na, ^{133}Ba, and ^{207}Bi, have been recently revised. This revision was undertaken due to discrepancies discovered in data taken before January 1973 on the NIST "4π" γ pressurized ionization chamber. Careful examination of the decay data indicates possible long-term instabilities in the measurement apparatus used at times previous to January 1973 for some radionuclides. These data have been thrown out and revised values for the half lives of these

radionuclides calculated. Also, corrections to the decay calculations for the ingrowth of ^{210}Bi in our radium reference standards have been made.

Results for ^{152}Eu, ^{154}Eu, ^{155}Eu, and ^{125}Sb have been revised slightly. These are significant for use of SRMs for precise efficiency calibrations and checks of spectrometry systems over a period of several years.

The results for the half lives of the many radionuclides measured over the last three decades are tabulated in a presentation being prepared for the 1991 ICRM symposium, with references to previous publications indicated. Comparisons with International Atomic Energy Agency (IAEA) Coordinated Research Program (CRP) values and recently reported measurements are also given.

Intercomparison of Commercial Scintillators (B. M. Coursey, J. M. Calhoun, J. T. Cessna, & L. L. Lucas)

Samples of commercially available scintillators have been tested for their long-term stability, using ^{3}H. The samples were measured over several months to determine the decrease in count rate as a function of scintillator type and the volume of water added.

One of the commercial scintillators with favorable long-term stability results was selected for additional stability studies with organic radio-labelled compounds of ^{3}H-hexadecane, ^{14}C-hexadecane and ^{99}Tc-pertechnetate. The intercomparison has been extended to following the samples on other commercial liquid-scintillation counters. The data are being analyzed as obtained and the results will be presented at the 1991 ICRM Conference in Madrid, Spain.

New Computer System (M. P. Unterweger & F. J. Schima)

A new computer system has been installed to handle the increases in data collection and data processing requirements of the Radioactivity Group, and all analysis programs have been transferred. This computer, a 68030-based super-micro computer with a large disk storage capacity, will result in the more efficient and rapid processing of data and allow access to large data bases, such as the ENSDF Radioactivity Data Base, which can be very useful for gamma-ray spectral analysis. Data can easily be transferred to and from this computer and individual PCs, allowing people to have the advantages of a large multi-user, multi-tasking system and also be able to take advantage of the word processing and other programs readily available on PCs. There are 10 users regularly logged onto the system, with 14 ports used for collecting data from up to six germanium spectrometers, four reference ionization chambers, a liquid-scintillation counter, mass balances, anticoincidence systems, and other data-collection systems in use in the Radioactivity Group.

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

Division 536, Ionizing Radiation

Marc F. Desrosiers organized the workshop, "Standards in EPR Spectroscopy" at NIST, Gaithersburg, MD, sponsored by the Office of Standard Reference Materials, December 7-8, 1989.

Kenneth G. W. Inn organized Workshop on Standard Phantoms for In-vivo Radioactivity Measurements, NIST, Gaithersburg, MD, February 13-14, 1990.

E. Dale McGarry organized NRC Meeting on Nuclear Reactor Vessel Work, NIST, Gaithersburg, MD, February 13-15, 1990.

William L. McLaughlin served on the Program Committee and as Chairman for Invited Speakers of the 1st International Workshop for Dosimetry Radiation Processing, St-Adele, Quebec, Canada, October 1989.

INVITED TALKS

Division 536, Ionizing Radiation

Berger, M. J., "Differences in the Multiple Scattering of Electrons and Positrons," Symposium on the Physics of Electron Transport, NIST, Gaithersburg, MD, April 2, 1990.

Bergtold, D. S., "Urinary Biomarkers in Post-Exposure Dosimetry," Third International Conference on Anticarcinogenesis and Radiation Protection; Dubrovnic, Yugoslavia, October 1989.

Bergtold, D. S., "Noninvasive Assays of Human Genetic Damage by GC/MS," International Symposium on DNA Damage and Repair in Human Tissues, Washington, DC, October 1989.

Bergtold, D. S., "Noninvasive Assays of Free Radical Damage in vivo," U.S. Department of Agriculture, Washington, DC, November 1989.

Bergtold, D. S., "SRM's for the Measurement of Damage to Genetic Material," International Symposium on Biological and Environmental Reference Materials; Orlando, FL, February 1990.

Bergtold, D. S., "Noninvasive Assays of Free Radical-Induced DNA Damage" National Cancer Institute Workshop on Oxidative Stress Status and Cancer Risk, Bethesda, MD, February 1990.

Bergtold, D. S., "In vivo Biomarkers of Free Radical Damage to DNA," Oxygen Society of Washington, DC, March 1990.

Bergtold, D. S., "Biomarkers of Oxidative Damage in Radiation Therapy," University of Massachusetts School of Medicine, Worcester, MA, March 1990.

Bergtold, D. S., "Urinary Biomarkers of Damage During Cancer Radiotherapy," Third International Conference on the Interactions of Radiation Therapy and Systemic Therapy, Monterey, CA, March 1990.

Bergtold, D. S., "Mechanisms of DNA Damage and its Detection in vivo," Human Nutrition Research Center at Tufts University, Boston, MA, March 1990.

Boswell, E., "The World of Low Temperatures-Cryogenics," Dunloggin Middle School, Columbia, MD, December 7, 1989.

Boswell, E., "The Structure of the Atom," Ellicott Mills Middle School, Ellicott City, MD, January 31, 1990.

Boswell, E., "Opportunities in Science," Ellicott Mills Middle School, Ellicott City, MD, January 31, 1990.

Boswell, E., "The World of Low Temperatures-Cryogenics," Ellicott Mills Middle School, Ellicott City, MD, January, 31, 1990.

Division 536, Invited Talks (cont'd)

Boswell, E., "The World of Low Temperatures-Cryogenics," Regional Institute for Children and Adolescents, Rockville, MD, February 20, 1990.

Boswell, E., "Opportunities in Science," Woods Academy, Bethesda, MD, April 6, 1990.

Boswell, E., Science Fair Judge, Maryvale Elementary, Rockville, MD, May 18, 1990.

Boswell, E., "Lasers and Optics," Brookhaven Elementary School, Rockville, MD, June 12, 1990.

Carlson, Allan D., "The Neutron Cross-Section Standards Evaluations for ENDF/B-VI," Winter Meeting of the American Nuclear Society, San Francisco, CA, November 27, 1989.

Collé, R., "Problems with Radon Measurements," Quality Assurance Seminar for the Radon Industry, American Association of Radon Scientists and Technologists, Mid-Atlantic Chapter, Gaithersburg, MD, April 18, 1990.

Collé, R., "Establishing a National Measurement Assurance Program for Radon," Second Seminar for the Study of Quality Assurance for the Radon Industry, American Association of Radon Scientists and Technologists, Mid-Atlantic Chapter, Rockville, MD, September 13, 1990.

Desrosiers, M. F., "ESR Detection of Irradiated Foods," Research & Development Associates Conference, Boston, MA, October 1989.

Desrosiers, M. F., "Alanine Dosimetry at NIST" IAEA Coordinated Research Program on "Alanine Dosimetry at the Radiation Therapy Level," Vienna, Austria, May 1990.

Desrosiers, M. F., "ESR Dosimetry: Food Irradiation, Radiation Accidents, and Radiation Therapy," National Cancer Institute, Frederick, MD, May 1990.

Desrosiers, M. F., "QC/QA Measurements on Irradiated Foods," Institute of Food Technologists Annual Meeting, Anaheim, CA, June 1990.

Desrosiers, M. F., "Detection and Dosimetry of Irradiated Foods," IAEA Coordinated Research Program on "Analytical Detection Methods for Irradiated Treatment of Foods" Jachranka, Poland, June 1990.

Desrosiers, M. F., "EPR Dosimetry Following a Radiation Accident," and "Novel Spin Trapping Studies of Nitrosoamine Free Radicals," Rocky Mountain Analytical Conference, Denver, CO, August 1990.

Hubbell, J. H., "Agenda Item 5: Which Parameters (Energy Level, Dose Level) Are Necessary for Cargo Surveillance with Ionizing Radiation or any other Alternative?" WHO/IAEA Consultation on Food Safety Aspects Relating to the Application of X-Ray Surveillance Equipment, Neuherberg/Munich, FRG, November 17, 1989.

Division 536, Invited Talks (cont'd)

Hubbell, J. H., "Food Safety Aspects Relating to the Application of High Energy (Above 5 MeV) X-Ray Surveillance Equipment," Division of Radiological Protection, Bhabha Atomic Research Center, Bombay, India, January 19, 1990.

Hubbell, J. H., "Radiometric Gauging (Metrology) in Industry, Agriculture, and Medicine," Physics Dept., Bose Institute, Calcutta, India, January 22, 1990.

Hubbell, J. H., "Food Safety Aspects Relating to the Application of High Energy (Above 5 MeV) X-Ray Surveillance Equipment," Variable Energy Cyclotron Complex, Calcutta, India, January 22, 1990.

Hubbell, J. H., "The NIST X-Ray Cross Section Data Base," Physics Dept., Visva-Bharati University, Santiniketan, India, January 25, 1990.

Hubbell, J. H., "Food Safety Aspects Relating to the Application of High Energy (Above 5 MeV) X-Ray Surveillance Equipment," Physics Dept., Panjab Univ., Chandagarh, India, January 29, 1990.

Hubbell, J. H., "The NIST X-Ray Cross Section Data Base," Physics Dept., Punjabi Univ., Patiala, India, January 30, 1990.

Hutchinson, J. M. R. (with M. P. Unterweger and P. A. Hodge), "Development of Large Area Alpha-Particle and X-Ray Counting Systems for Traceability Measurements," Conference on Calibration and Test Equipment, Redstone Arsenal, Huntsville, AL, June 14-15, 1990.

Inn, K. G. W., "Ionizing Radiation Secondary Laboratories," USCEA Power Plants Steering Committee, NIST, Gaithersburg, MD, October 19, 1989.

Inn, K. G. W., "NIST Traceability for In-Vivo Radioactivity Measurements," Bioassay, Analytical, and Environmental Radiochemistry Conference, Charleston, SC, October 30, 1989.

Inn, K. G. W. (with H. T. Heaton, II, E. H. Eisenhower, and B. M. Coursey), "NIST's Office of Radiation Measurement," Bioassay, Analytical, and Environmental Radiochemistry Conference, Charleston, SC, October 30, 1989.

Inn, K. G. W. (with B. M. Coursey, E. H. Eisenhower, M. D. Walker, H. T. Heaton, II, and K. C. Duvall) "National Ionizing Radiation Secondary Laboratory System," Conference on Actinides and Long-Lived Radionuclides in Environmental and Biological Samples, Bombay, India, January 29-February 2, 1990.

Inn, K. G. W., "NIST Ocean Sediment SRM," Environmental Radioactivity Measurements Standards and Reference Material Conference, National Physical Laboratory, United Kingdom, September 17, 1990.

Inn, K. G. W. (with H. T. Heaton, II, K. C. Duvall, B. M. Coursey, and E. H. Eisenhower), "The Role of the Office of Radiation Measurement in Quality Assurance," 6th International Symposium

on Environmental Radiochemical Analysis, Royal Society of Chemistry, University of Manchester, United Kingdom, September 20, 1990.

Karam, L. R., "Ascorbate Facilitated Hydroxy Radical Generation by Haber-Weiss Reaction in vitro," at the 3rd International Conference on Anticarcinogenesis and Radiation Protection, Dubrovnik, Yugoslavia, October 1989.

Karam, L. R., "Hydroxylated Phenylalanine as a Marker of Hydroxy Radical Generation," 3rd International Conference on Anticarcinogenesis and Radiation Protection, Workshop on Free Radical Processes in Biology and Medicine (co-chairman), Dubrovnik, Yugoslavia, October 15-21, 1989.

Karam, L. R., "Modification of Deoxyribose-Phosphate Residues by Ataxia Telangiectasia Cell Extracts," UCLA 1990 Symposium on Ionizing Radiation Damage to DNA: Molecular Approaches, Lake Tahoe, CA, January 16-21, 1990.

McLaughlin, W. L., "Radiation Dosimetry-Overview and Underview," 3M Technical Forum, sponsored by Industrial & Electronic Sector Research Lab., 3M Center, St. Paul, MN, October 18, 1989.

McLaughlin, W. L., "Dosimetry for Low Energy Electron Machine Performance and Process Control," RadTech '90 North American Conference, Chicago, IL, March 28, 1990.

McLaughlin, W. L., "Development of Calorimetric Standards for Calibration of High-Dose Electron-Beam Dosimeters," IAEA Coordinated Research Meeting on Development of Quality Control for Particle-Beam Radiation Processing, Institute of Isotopes, Hungarian Academy of Sciences, Budapest, Hungary, April 3, 1990.

McLaughlin, W. L., "Chemical Dosimetry," School of Chemistry Seminar, University of Merida, Yucatan, Mexico, April 10, 1990.

McLaughlin, W. L., "Radiation Measurements for Quality Control in Industry and Agriculture," School of Engineering Seminar, University of Merida, Yucatan, Mexico, April 11, 1990.

McLaughlin, W. L., "Radiation Dose Distributions in Food Packages," and "The IAEA International Dose Assurance Service," Food Irradiation Process Control School, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Canadian Irradiation Center, Laval, Quebec, Canada, July 11, 1990.

Seltzer, S. M., "Electron-Photon Monte Carlo Calculations: the ETRAN Code," Symposium on the Physics of Electron Transport, NIST, Gaithersburg, MD, April 2, 1990.

Seltzer, S. M., "Progress on Electron Transport Calculations with Biomedical and Environmental Applications," DoE Radiological and Chemical Physics Contractor Meeting, Berkeley, CA, June 28, 1990.

Division 536, Invited Talks (cont'd)

Simic, M. G., "Urinary Biomarkers in Radiation Therapy of Cancer," Free Radicals and Cancer, Tubingen, Germany, December 8-9, 1989.

Simic, M. G., "SRMS for the Measurements of Damage to Genetic Materials," 4th International Symposium on Biological and Environmental Reference Materials, Orlando, FL, February 5-8, 1990.

Simic, M. G., "Urinary Biomarkers of DNA Damage," Biological Effects of Dietary Restrictions, Washington, DC, March 5-7, 1990.

Simic, M. G., "Neurophysiological Antioxidants," Mechanisms of Oxidative Injury to the Brain and Cardiovasculature, Bethesda, MD, March 31, 1990.

Simic, M. G., "Peroxidation Mechanisms of Fatty Acid Micelles and the Resulting Damage to Mucosa," 6th International Congress of Mucosa Immunology, Tokyo, Japan, July 22-27, 1990.

Walker, M. L., and McLaughlin, W. M., "Laser Telemetering Dosimetry System," RadTech '90 North American Conference, Chicago, IL, March 25-29, 1990.

Walker, M. L., and McLaughlin, W. L., "Laser Telemetering Dosimetry System," NOBCChE 17th Annual Conference, San Diego, CA, April 9-14, 1990.

Wasson, Oren A., "Experience in Data Analysis using Small Numbers," Oak Ridge National Laboratory, TN, March 14, 1990.

Michael G. Simic organized conference, "Third International Conference on Anticarcinogenesis," Dubrovnik, Yugoslavia, October 15-20, 1989.

Stephen M. Seltzer, R. S. Caswell, Bert M. Coursey organized the Symposium on the Physics of Electron Transport, NIST, Gaithersburg, MD, April 2-3, 1990.

PUBLICATIONS

Division 536, Ionizing Radiation

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Barrett, J. H., Glover, K. M., McLaughlin, W. L., Harpe, P. H. G., Watts, M. J., and Wittaker, B., "Intercomparison Studies of Gamma-Ray Absorbed Dose Using Radiochromic Dye Films and Red 4034 Perspex," Radiat. Phys. Chem., 505-507 (1990).

Behrens, J. W. and Carlson, A. D., Editors of the Proceedings of the Conference entitled "Fifty Years with Nuclear Fission," NIST, Gaithersburg, MD, April 25-28, 1989 published by the American Nuclear Society, Inc., La Grange Park, Illinois (1989). 978 pp.

Bergtold, D. S., and Simic, M. G., "Background Levels of DNA Damage," Free Radical Res. Comm. 6, 195-198 (1989).

Bergtold, D. S., Berg, C. D., and Simic, M. G., "Urinary Biomarkers in Radiation Therapy of Cancer," Antioxidants in Therapy and Preventive Medicine, I. Emerit, L. Packer, and C. Auclair, eds. (Plenum: New York) 311-316 (1990).

Bigbee, P. D., Sarin, R. S., Humphreys, J. C., Eubanks, W. G., Sun, D., Hocken, D. G., Thornton, A., Adams, D. E., and Simic, M. G., "Inactivation of Human Immunodeficiency Virus (HIV) by Ionizing Radiation in Body Fluids and Serological Evidence," J. Forensic Science 34,, 1303-1310 (Nov. 1989).

Bockhoff, K. H., Carlson, A. D., Wasson, O. A., Harvey, J. A., and Larson, D. C., Electron Linear Accelerators for Fast Neutron Data Measurements in Support of Fusion Energy Applications, Nuc. Sci. Eng. 106, 192-207 (1990).

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Carlson, A., Poenitz, W. P., Hale, G. M., and Peelle, R., "The Neutron Cross Section Standards Evaluations for ENDF/B-VI," Trans. Am. Nucl. Soc. 60, 604 (1989).

Caswell, R. S. and Coyne, J. J., "Microdosimetry of Radon and Radon Daughters," Radiat. Prot. Dosim. 31, No. 1/4, 395-398 (1990).

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Collé, R., Hutchinson, J. M. R., and Unterweger, M. P., "The NIST Primary Radon-222 Measurement Systems," J. Res. NIST 95, 155-165 (1990); Nuc. Sci. Eng. 106, 192-207, (1990); Sci. 34 1303-1310 (1989).

Coursey, B. M., Hirshfeld, A. T., Hoppes, D. D., Judge, S. M., Woods, D. H., Woods, M. J., Funck, E., Tuck, A. G., "Standardization and Decay Scheme of Thallium-201," Appl. Radiat. Isot. 41, 289 (1990).

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Coyne, J. J., Gerstenberg, H. M., Hansen, J., and Zoetelief, J., "Calculations of the Relative Effectiveness of Alanine for Neutrons with Energies up to 17.1 MeV," Radiat. Prot. Dosim. 31, No. 1/4, 85-89 (1990).

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Desrosiers, M. F. and McLaughlin, W. L., "Examination of Gamma-Irradiated Fruits and Vegetables by Electron Spin Resonance Spectroscopy," Radiat. Phys. Chem. 34, 895-898 (1989).

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Desrosiers, M. F., "Assessing Radiation Dose to Food," Nature 345, 485 (1990).

Eisenhauer, C. M., "Review of Scattering Corrections for Calibration of Neutron Instruments," Radiation Protection Dosimetry 4, 253-262 (1989).

Division 536, Publications (cont'd)

Eisenhauer, C. M., "Slab Transmission and Reflection for Point Source and Point Detector," Am. Nuc. Soc. Trans. 62, 449 (Nov. 1990).

Farahani, M. and McLaughlin, W. L., "Radiochromic Dye Dosimeter Solutions as Reference Measurement Systems," Radiat. Phys. Chem. 32, 683-690 (1989).

Farahani, M. and McLaughlin, W. L., "Radiation-Induced Cross Links Between Thymine and 2-Deoxyribose," Radiat. Phys. Chem. 32, 731-734 (1989).

Farahani, M., Liang, J. H., and McLaughlin, W. L., "Radiochromic Dosimeter Solutions for Reference Dosimetry," Appl. Radiat. Isot. 41, No. 1, 5-11 (1990).

Farahani, M., Eichmiller, F. C., and McLaughlin, W. L., "Measurement of Absorbed Doses near Metal and Dental Material Interfaces Irradiated by X- and Gamma-Ray Therapy Beams," Phys. Med. Biol. 35, 369-385 (1990).

Gilliam, D. M., Greene, G. L., and Lamaze, G. P., "Absolute Neutron Counting Based on B-10 Alpha-Gamma Coincidence Methods," Nucl. Instr. & Meth. Phys. Res. A284, 220 (Nov. 1989).

Gilliam, D. M., Spiegel, V., and Eisenhauer, C. M., Quang Eiping, Briesmeister, Judith F., and Jabo Tang, "Neutron Leakage Benchmark for Criticality Safety Research," Am. Nuc. Soc. Trans. 62, 340 (Nov. 1990); Isotopes 41, 5-11 (1990).

Hoppes, D. D., "Report on the 1989 Meeting of the Radionuclide Measurements Section of the Consultative Committee on Standards for the Measurement of Ionizing Radiations," J. Res. Nat'l. Inst. Stand. Tech. 94, No. 6, 363-366 (Nov.-Dec. 1989).

Hoppes, D. D., "Demonstrated Measurement Traceability for Nuclear Power Radiochemistry Departments," Radioactivity & Radiochemistry 1, No. 1, 9 (Winter 1990).

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Hutchinson, J.M.R. and Collé, R., eds. "Radon Measurement Standards and Calibrations," J. Res. NIST 95 (1990) (Special Issue).

Inn, K.G.W., Heaton, H. T. II, Duvall, K. C., and Coursey, B. M. "National Ionizing Radiation Secondary Calibration Laboratory System," Radioactivity and Radiochemistry 1, (1), 17-22 (1990).

Inn, K.G.W. and Kramer, G. H., Proceedings of the Workshop on: Standard Phantoms for In-Vivo Radioactivity Measurement, Human Monitoring Laboratory Technical Document, HMLTD-90-4, National Institute of Standards and Technology, February 13-15 (1990).

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Division 536, Ionizing Radiation

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Barnea, G., Navon, G., Ginzburg, A., Politch, J., Roehrig, H., Dick, C., and Placious, R., "Use of Storage Phosphor Imaging Plates in Portal Imaging and High Energy Radiography, I. The Effect of Metallic Intensifying Screens on The Sensitivity," (submitted to Medical Physics).

Bartko, J., Ruddy, F. H., Schoch, K. F., Congedo, T. V., and McGarry, E. D., "A Novel On-Line Neutron Dosimeter Based on a Conducting Polymer," 7th ASTM/Euratom Symposium on Reactor Dosimetry, Strasbourg, France, 27-30 August 1990 (in press).

Berger, M. J., "Modification of electron and positron sources due to reflection of particles from backing material," (to be published in ANS Transactions).

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and Alpha Particles," Report of the International Commission on Radiation Units and Measurements (accepted).

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Deasy, J. O. and Soares, C. G., "Extrapolation Chamber Measurements on Ophthalmic Applicators" (in preparation).

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Khan, H. M., Farahani, M., and McLaughlin, W. L., "A Radiochromic Film Dosimeter for Gamma Radiation in the Absorbed Dose Range 0.1 to 10 kGy," Radiat. Phys. Chem (in press).

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TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 536, Ionizing Radiation

Martin J. Berger

Chairman, International Commission on Radiation Units and Measurements (ICRU) Report Committee on Stopping Power.

Consultant, ICRU Report Committee on Material Equivalent and Tissue Substitutes.

Participant in the International Atomic Energy Agency (IAEA) Coordinated Research Programme on Atomic and Molecular Data for Radiotherapy.

Jacqueline M. Calhoun

Member, U.S. Council for Energy Awareness (USCEA)-NIST Standards Program Committee.

Member, Subcommittee USCEA/NIST Measurement Assurance Program for the Nuclear Power Industry.

Member, Subcommittee USCEA/NIST Measurement Assurance Program for the Nuclear Medical Industry.

Co-Chair, Publicity Committee of the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChe).

Member, Advisory Panel on Radiopharmaceuticals, U. S. Pharmacopeia.

Member, National Institute of Standards and Technology, Day Care Scholarship Committee.

Member, National Institute of Standards and Technology Handicap Committee.

EEO Coordinator, National Measurement Laboratory.

Allan D. Carlson

Chairman, Standards Subcommittee, Cross Section Evaluation Working Group (CSEWG).

Member, Evaluation Committee of CSEWG.

Member, Data Status and Requests Subcommittee of CSEWG.

Chairman, Nuclear Energy Agency Nuclear Data Committee (NEANDC)
Working Group on the $^{10}B(n,\alpha)$ Cross Section Standard.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd)

Randall S. Caswell

Chairman, Science Panel, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC), Office of Science and Technology Policy.

Alternate Member, Main Committee, CIRRPC.

Member, Science Subpanel on Recommendations on Radiation Protection, CIRRPC.

Chairman, Consultative Committee for Ionizing Radiations (CCEMRI), Conférence Générale des Poids et Mesures, Section on Neutron Measurements (Section III), Paris, France (through December 1989).

Member, National Council on Radiation Protection and Measurements (NCRP).

Member, Selection Committee for the Presidency of the NCRP.

Member and Secretary, ICRU.

Sponsor, ICRU Report Committee on Stopping Power for Protons and Alpha Particles.

Sponsor, ICRU Report Committee on Stopping Power for Heavy Ions.

Sponsor, ICRU Report Committee on Absorbed Dose Standards for Photon Irradiation and Their Dissemination.

Sponsor, ICRU Report Committee on Clinical Dosimetry for Neutrons (Physics).

Sponsor, ICRU Report Committee on In-Situ Gamma-Ray Spectrometry in the Environment.

Ronald Collé

Member, Radon Working Group, Interagency Committee on Indoor Air Quality.

Bert M. Coursey

Member, International Committee for Radionuclide Metrology (ICRM) Life Sciences Working Group.

Member, American National Standards Institute (ANSI) Committee N42.02 on Nuclear Instruments, Procedural Standards for Calibration of Detectors for Radioactive Measurements.

Alternate Member, Science Panel, CIRRPC.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd)

Bert M. Coursey (cont'd)

Delegate to Section I, Consultative Committee for Ionizing Radiations (CCEMRI), Conference Generale des Poids et Mesures, Paris, France.

Marc F. Desrosiers

Member, IAEA Coordinated Research Program on "Alanine Dosimetry at the Radiation Therapy Level."

Chairman, Electron Spin Resonance subcommittee, IAEA Coordinated Research Program on "Analytical Detection Methods for the Irradiated Treatment of Foods".

Program Chairman, Washington Electron Paramagnetic Resonance Discussion Group.

Charles E. Dick

Member, Technical Organizing Committee, Industrial Applications, International Conference on the Applications in Research and Industry.

Charles M. Eisenhauer

Member, CIRRPC Science Panel; Chairman, Subpanel on Predisaster Planning for Human Health Effects Research.

Member, Working Group 2, Reference Radiations Subcommittee 2, Technical Committee 5, International Standards Organization.

Member, National Academy of Sciences (NAS)-Nuclear Regulatory Commission (NRC) Advisory Committee on the Radiation Effects Research Foundation; Advisory Dosimetry Subcommittee.

Member, American Nuclear Society (ANS) Standards Committee Working Group on Gamma-Ray Attenuation Data.

David M. Gilliam

Member, CCEMRI Section on Neutron Measurements (Section III), Conférence Générale des Poids et Mesures, Paris, France.

James A. Grundl

Member, NCRP Task Group SC-63 on Public Knowledge About Radiation Emergencies.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd)

James A. Grundl (cont'd)

Member, American Society for Testing and Materials (ASTM) Subcommittee E10.05 on Nuclear Radiation Metrology.

Member, CIRRPC Subpanel on Public Education.

Dale D. Hoppes

Secretary, International Committee for Radionuclide Metrology (ICRM).

Member, ICRM Beta- and Gamma-Ray Spectrometry Working Group.

Member, U.S. Council for Energy Awareness (USCEA)-NIST Standards Program Committee.

Member, International Committee of Weights and Measures (BIPM), Consultative Committee on Standards for Measuring Ionizing Radiations, Subcommittee Section II: Radionuclide Measurements.

Member, ANSI Subcommittee N42.2 on Procedural Standards for Calibration of Detectors for Radioactive Materials.

John H. Hubbell

Chairman (1984-1990), General Radiation Protection Committee, Health Physics Society Standards Committee.

Member, American Nuclear Society Standards Committee Working Group ANS 6.4.3 to develop American National Standard ANSI/ANS-6.4.3-1990: Gamma-Ray Attenuation Coefficients and Buildup Factors for Engineering Materials (Completed and submitted to ANSI-N17 Oct. 2, 1990).

Consultant, Lawrence Berkeley Laboratory (LBL)/European Center for Nuclear Research (CERN) Particle Data Group, for biennial Phys. Lett. B "Review of Particle Properties" and LBL/CERN Particle Properties Data Booklet."

Consultant, Lawrence Livermore National Laboratory, to provide photon interaction data for the LLNL Evaluated Nuclear Data Library (ENDL).

Consultant, ICRU.

Secretary, International Union of Crystallography (IUCr) Commission on Crystallographic Apparatus Task Group on X-Ray Attenuation.

Member, DoE CSEWG Subcommittee on Shielding.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd)

John H. Hubbell (cont'd)

Consultant, World Health Organization, on Food Safety Aspects of Application of Megavoltage X-Ray Cargo Surveillance Equipment. Chair, WHO/IAEA Consultation on this topic.

Executive Councilor, International Radiation Physics Society.

Member, International Advisory Board, 5th International Symposium on Radiation Physics, Dubrovnik, June 10-14, 1991.

Jimmy C. Humphreys

Secretary, ASTM E10.07 Subcommittee, Ionizing Radiation Dosimetry and Radiation Effects on Material and Devices.

Member, ASTM Subcommittee E10.01 Dosimetry for Radiation Processing.

Member, ASTM Subcommittee F1.11, Hardness Assurance of Electronics.

Member, Association for the Advancement of Medical Instrumentation (AAMI) subcommittee task groups on dosimetry of gamma and electron beam sterilization of medical products and devices.

J. M. Robin Hutchinson

Member, ANSI Committee on Nuclear Instruments and Detectors.

Secretary, ANSI Subcommittee N42.2 on Procedural Standards for Calibration of Detectors for Radioactivity Measurements.

Secretary, ANSI N42.2: "Radioactivity Measurements."

Chairman, International Committee for Radionuclide Metrology (ICRM) Subcommittee on Low-level Techniques.

Chairman, Ad hoc ICRM Committee to draft "Guidelines for International Acceptances of Radioactivity Calibration Sources."

Kenneth G. W. Inn

Member, ANSI N42.02, Quality Assurance for Radiochemistry Laboratories.

Member, ASTM Committee C26.05.01, Methods for Test, Environmental Methods.

Member, ASTM Committee D19, Water, Radioactivity Test Methods.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd)

Robert Loevinger

Member, Medical Internal Radiation Dose Committee, Society of Nuclear Medicine.

Consultant, American Association of Physicists in Medicine (AAPM) Radiation Therapy Committee.

Member, AAPM Radiation Therapy Committee Task Group 3, Accredited Dosimetry Calibration Laboratories.

Wilfrid B. Mann

Member, ANSI-INMM Working Group INNM 8.04 Calibration Technique for the Calorimetric Assaying of Plutonium-Bearing Solids applied to Nuclear Materials Control.

Member, ANSI N42.2, Radioactivity Measurements.

ISO TC 85/SC2/WG4, Surface Contamination (Radioactivity).

Honorary Council Member, NCRP.

Chairman, NCRP Committee 18A, Standards and Measurement of Radioactivity for Radiological Use.

Member, By-laws Committee, ICRM.

Life Member, ICRM.

Emmert D. McGarry

Member, ASTM Committee E10; Subcommittee E10.05, Nuclear Radiation Metrology.

Chairman, Awards Committee of ASTM Subcommittee E10.05.

Member, Planning Committee for the 9th ASTM-EURATOM Symposium on Reactor Dosimetry.

William L. McLaughlin

Technical Advisor, Council of Europe Parliamentary Assembly, Work Group on Aerospace Physiology, Medicine, and Radiation Measurement.

Technical Advisor, Council of Europe Parliamentary Assembly, Work Group on Space Biophysics.

Member, R & D Associates Committee on Irradiated Food Products.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd)

William L. McLaughlin (cont'd)

Member, IAEA Advisory Group on High Dose Measurement and Standardization for Radiation Processing.

Member, AAMI Subcommittee on Radiation Sterilization Dosimetry (Working Groups on Gamma Ray Sterilization and Electron Beam Sterilization).

Technical Advisor, NCRP Scientific Committee 63, Radiation Exposure Control in a Nuclear Emergency.

Science and Technology Consultant, CIRRPC.

Chairman, IAEA Advisory Panel on Electron Beam Dosimetry for Industrial Radiation Processing.

Member, IAEA Advisory Panel on Guidelines on Dosimetry for Industrial Radiation Processing.

Member of Organizing Committee and Chairman for Invited Speakers for 2nd International Workshop on Dosimetry for Radiation Processing, University of Maryland, College Park, Maryland.

Chairman, 3rd International Symposium on ESR Dosimetry and Applications, NIST, October 1991.

Member, ASTM Subcommittee E10.07 on Ionizing Radiation Dosimetry and Radiation Effects on Materials and Devices.

Member, Ad-Hoc Interdepartmental Committee on Food Irradiation (Secretariat, Department of Commerce).

Francis J. Schima

Research Associate Member, IAEA, Coordinated Research Program on Gamma-ray Standards for Detector Efficiency Calibration.

Member, ICRM Working Group on Gamma- and Beta-ray Spectrometry.

Scientific and Technical Consultant, CIRRPC.

Roald A. Schrack

Member, Environmental Protection Agency Interagency Working Group on Residual Radioactivity.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd)

Robert B. Schwartz

Member, ICRU Report Committee on Practical Determination of Dose Equivalent.

Chairman, Neutron Sub-Group, ISO TC 85/SC 2/WG 2.

Stephen M. Seltzer

Chairman, Organizing Committee, Symposium on the Physics of Electron Transport, NIST, Gaithersburg, MD.

Member, ICRU Report Committee on Stopping Power.

Consultant, ICRU Report Committee on Material Equivalent and Tissue Substitutes.

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Michael G. Simic

Member of Council of Agricultural Science and Technology (CAST).

Member of editorial board of Free Radical Biology and Medicine.

Secretary General of the Oxygen Society.

Member of the Advisory Board Critical Reviews of Sulfhydryl Chemistry.

Christopher G. Soares

Voting member, Health Physics Scientific Subcommittee Work Group for the revision of ANSI N13.11, "Personnel Dosimetry Performance--Criteria for Testing."

ISO TC 85/2/2/0, International Standards Organization sub-group for the revision of ISO 6980, "Reference beta radiations for calibrating dose- meters and doseratemeters and for determining their response as a function of beta radiation energy," US Tech. expert appointed by ANSI.

Marlon L. Walker

Chairman, NOBCCHE Committee for New Directions and Plans.

Member, SEBA board.

Michael P. Unterweger

Member, ASTM Committee D22 on Sampling and Analysis of Atmospheres.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd)

Oren A. Wasson

Member, DoE Nuclear Data Committee.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 536, Ionizing Radiation

R. Collé advised and served as a reviewer for the DOE Radon Research Program.

R. Collé collaborated with and assisted Rad Elec, Inc., one of the major U.S. radon instrument manufacturers, in establishing a calibration protocol for passive, integrator radon monitors using prototype polyethylene-encapsulated radium-solution standards.

J. A. Grundl is guest curator for an exhibit entitled "Lady Godiva and the Realities of Nuclear Energy" at the National Atomic Museum in Albuquerque, NM.

J. H. Hubbell responded to 238 inquiries received at NIST from industrial, medical and academic researchers and administrators, including requests for NIST/OSRD databases, publications, technical information and advice, and related services.

J. H. Hubbell provided x-ray interaction data to and chaired a WHO/IAEA Consultation on use of megavoltage x-ray large-cargo surveillance systems.

J. H. Hubbell provided NIST-side monitoring and principal-investigator services to the joint NIST/India Special Foreign Currency (SFCP) Project at Panjab University, Chandigarh: "Measurement, Theoretical Analysis, and Compilation of Photoionization and Fluorescence Yield Data for X-Ray Dosimetric and Analytical Applications," including principal-investigator visitations in Chandigarh and at NIST and publication of a joint work on L-shell fluorescence yields.

E. D. McGarry provides consultation to Materials Engineering Branch of the Nuclear Regulatory Commission regarding benchmarking of pressure vessel surveillance dosimetry.

E. D. McGarry is now also providing consultation to the Materials Engineering Branch of the NRC with respect to radiation damage of structural components of commercial nuclear reactors. Current consultation deals with components of the TROJAN PWR reactor in Portland, Oregon.

R. B. Schwartz and E. W. Boswell collaborated with health physicists and consultants from the Illinois Power Company to calibrate a Bonner sphere set, and to test a new system for data taking and spectral unfolding.

R. B. Schwartz and E. W. Boswell worked with health physicist from New Hampshire Yankee (Seabrook) to test, and understand the use of, a neutron field spectrometer based on a tissue equivalent proportional counter.

Division 536, Major Consulting and Advisory Services (cont'd)

S. M. Seltzer collaborated with scientists at the NASA Goddard Space Flight Center (and the US Geological Survey) on the theoretical and experimental development of a pattern-recognition approach to XRF analysis for the compositional classification of geological samples (with applications to the Mars Rover Mission), metal-alloys, and paints.

S. M. Seltzer provided close consultation to members of the Simulation Division, Sandia National Laboratory, Albuquerque, NM, on the incorporation of recently-developed electron-photon cross sections and sampling algorithms into their Monte Carlo codes.

JOURNAL EDITORSHIPS

Division 536, Ionizing Radiation

B. M. Coursey, Editor, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes.

B. M. Coursey, Editor, International Journal of Radiation Applications and Instrumentation, Part B. Nuclear Medicine and Biology.

B. M. Coursey, Editorial Board, Radioactivity and Radiochemistry.

C. E. Dick, Member, Editorial Board, Industrial Metrology.

M. F. Desrosiers, Consulting Editor, Special Issue: "ESR Dosimetry and Applications" in Applied Radiation and Isotopes, 40, No. 10-12, 1989.

J. H. Hubbell, Editor, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes.

J. H. Hubbell, W. B. Mann, and W. L. McLaughlin, Special Issue: "Industrial Radiation and Radioisotope Measurement Applications," in Applied Radiation and Isotopes 41, Nos. 10/11 (1990).

W. B. Mann, Consulting Editor, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes.

W. B. Mann, Consulting Editor, International Journal of Radiation Applications and Instrumentation, Part B. Nuclear Medicine and Biology.

W. L. McLaughlin, Editor in Chief, North America, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes.

W. L. McLaughlin, Editorial Board, Radiation Physics and Chemistry.

M. G. Simic, International Editorial Board, Free Radical Biology and Medicine.

M. G. Simic, International Editorial Board, Mutation Research, DNA-Aging Section.

TRIPS SPONSORED BY OTHERS

Division 536, Ionizing Radiation

Martin J. Berger traveled to Schloss Elmau, Germany to participate in the Annual Meeting of the ICRU, as Chairman of the Stopping Power Committee. ICRU paid all expenses. (September 8-15, 1990)

David Bergtold traveled to Worcester, Massachusetts to give an invited talk, "Biomarkers of Oxidative Damage in Radiation Therapy." Lodging paid by the University of Massachusetts. (March 15, 1990)

David Bergtold traveled to Boston, Massachusetts to give an invited talk, "Mechanisms of DNA Damage." Lodging paid by Tufts University, Massachusetts. (March 16, 1990)

Jacqueline M. Calhoun traveled to Budapest, Hungary for a working visit to the OMH as part of the U.S.-Hungary Cooperative Agreement. Air fare, lodging, and subsistence were provided. (May 7, 1990 - May 12, 1990)

Randall S. Caswell traveled to Schloss Elmau, West Germany to attend the Annual Meeting of the International Commission on Radiation Units and Measurements (ICRU). Partial subsistence provided by ICRU. (September 8-15, 1990)

Ronald Collé, traveled to San Francisco, California to serve as a reviewer for the DoE Radon Research Program. All expenses were paid by DoE. (May 1990)

Bert M. Coursey traveled to Oxford, Harwell, London, and Teddington, United Kingdom to attend an Editorial Board meeting and to discuss intercomparisons with NIST and NPL on High Dose chemical dosimeters. Round-trip airfare and partial subsistance were provided by Pergamon Press, Ltd. (June 11-21, 1990)

Marc F. Desrosiers traveled to Jachranka, Poland to participate in IAEA Coordinated Research Program on "Analytical Detection Methods for the Irradiated Treatment of Foods". Travel and subsistence were provided by the IAEA. (June 1990)

Dale D. Hoppes paid a working visit to the Institute of Physics, University of Novi Sad, Yugoslavia. Round-trip airfare and expenses while in Yugoslavia were provided by the Joint Yugoslav-U.S. Project. (May 26-June 2, 1990)

John H. Hubbell traveled to Neuherberg/Munich, FRG to chair and present an invited talk at a WHO/IAEA Consultation: "Food Safety Aspects Relating to the Application of [Megavoltage] X-Ray Surveillance Equipment." All expenses were paid by the World Health Organization. (November 13-17, 1989)

John H. Hubbell traveled to Chandigarh, India as NIST-side monitor and principal investigator of the joint NIST/India Special Foreign Currency Program (SFCP) project "Measurement, Theoretical

Division 536, Trips Sponsored by Others (cont'd)

John H. Hubbell traveled to Chandigarh, India as NIST-side monitor and principal investigator of the joint NIST/India Special Foreign Currency Program (SFCP) project "Measurement, Theoretical Analysis, and Compilation of Photoionization and Fluorescence Yield Data for X-Ray Dosimetric and

Analytical Applications" at Panjab University. In addition, he participated in an Executive Council Meeting of the International Radiation Physics Society (IRPS) at BARC, Bombay, and gave lectures there and in Calcutta, Santiniketan, Chandigarh, and Patiala. The SFCP paid airfare and expenses in New Delhi (7 days total); the remaining subsistence expenses were paid by BARC, Bombay (6 days), Bose Inst. and VEC, Calcutta (4 days), Visva-Bharati Univ., Santiniketan (2 days), and Panjab Univ., Chandigarh (5 days). (January 11 to February 3, 1990)

John H. Hubbell traveled to Oxford, UK for an Editorial Board meeting with the publishers, Pergamon Press, of Applied Radiation and Isotopes. All expenses paid by Pergamon Press. (June 12-13, 1990)

Kenneth G. W. Inn traveled to Richland, Washington to serve on the U.S. Transuranium and Uranium Registries Advisory Committee to review the technical progress and program for the Hanford Environmental Health Foundation. (November 16-17, 1989)

Lisa R. Karam traveled to Lake Tahoe, California to give an invited talk, "Doxyribase-Phosphate Residues by Ataxia-Telangiectasia Cell Extracts." Lodging and partial subsistence paid for by UCLA. (January 16-21, 1990)

Lisa R. Karam traveled to London, United Kingdom to continue a Fellowship and collaboration at the Imperial Cancer Research Fund. Lodging and meals paid for by the Imperial Cancer Research Fund. (February 1-28, 1990)

William L. McLaughlin traveled to Budapest, Hungary to chair Coordinated Research Meeting on Quality Control on Particle Beam Radiation Processing. All expenses paid by the International Atomic Energy Agency, Vienna, Austria. (March 31 - April 7, 1990)

William L. McLaughlin traveled to Montreal, Canada, to teach a one-day course at the Food Irradiation Process Control School. All expenses paid by International Atomic Energy Agency. (June 10, 1990)

William L. McLaughlin traveled to London, England to co-chair an International Editors Meeting of Pergamon Press, Ltd. Air fare and subsistence paid by Pergamon Press, Ltd. (June 11-13, 1990)

Robert B. Schwartz traveled to Vienna, Austria to attend a working meeting of the ICRU Report Committee on Practical Determination of Dose Equivalent. The ICRU paid the full cost of the trip. (November 11-14, 1989)

Michael G. Simic traveled to Philadelphia, Pennsylvania to give an invited talk, "Underlying Mechanism of Food Irradiation." All expenses paid by the United States Department of Agriculture, Washington, DC. (November 12-14, 1989)

Division 536, Trips Sponsored by Others (cont'd)

Michael G. Simic traveled to Tokyo, Japan to conduct joint cooperative research on antioxidants. Lodging was paid for by the University of Tokyo. (February 4-24, 1990)

Michael G. Simic traveled to Mulheim, West Germany for collaborative research on the mechanisms of deoxyribonucleid acid strand breaks and antioxidants. Subsistence paid by Max Planck Institute. (April 21 - May 11, 1990)

Michael G. Simic traveled to Tokyo, Japan to give an invited talk, "Peroxidation Mechanisms of Fatty Acid Micelles and the Resulting Damage to Mucosa". All expenses paid by the International Conference on Mucosal Immunology, Tokyo, Japan. (July 25-27, 1990)

STANDARD REFERENCE MATERIALS

Division 536, Ionizing Radiation

Radioactivity Group

RADIOACTIVITY STANDARDS ISSUED - FY 1990

SRM	Radionuclide	Principal Calibration Use
4417L-J	Indium-111	Activity measurement of radiopharmaceuticals
4406L-K	Phosphorus-32	
4410H-P	Technetium-99m	
4407L-O	Iodine-25	
4401L-P	Iodine-131	
4412L-O	Molybdenum-99	
4415L-N	Xenon-133	
4416L-K	Gallium-67	
4404L-M	Thallium-201	
4400L-L	Chromium-51	
4275C	Long-Lived Mixed Point Sources	Germanium spectrometry systems in the energy range from 27 to 1596 keV
4276C	Long-Lived Mixed Solutions	Germanium spectrometry systems in the energy range from 27 to 1596 keV
4328	Thorium-229	Chemical yield monitor
4943	Chlorine-36	Chemical yield monitor
4222C	Carbon-14 Hexadecane	For the preparation of secondary standards for liquid scintillation counting
4325	Beryllium-10/9	Isotopic-ratio measurements
4334D	Plutonium-242	Tracer for radiochemical analysis
4233C	Cesium-242	Monitoring the status of fuel rods

Total Number of Radioactivity SRM's distributed: 727

CALIBRATION SERVICES PERFORMED

536, Ionizing Radiation

I. Radiation Interactions and Dosimetry Group

HIGH-DOSE CALIBRATIONS FY 1990

	CUSTOMER CLASSIFICATION	TYPE OF SERVICE	NO. OF CUSTOMERS	NO. OF TESTS PERFORMED	SERVICE FEE INCOME
1	Industrial:	A	34	206	68,993
	medical product	B	5	7	4,546
	sterilization	C	5	14	199
2	Industrial:	A	5	39	13,692
	electronic	B	4	14	7,636
	hardness testing	C	1	1	47
3	Industrial:	A	0	0	0
	polymer	B	0	0	0
	modification	C	0	0	0
4	National Laboratory:	A	0	0	0
	eletronic	B	2	3	1,701
	hardness testing	C	0	0	0
5	Dept. of Defense:	A	3	19	2,448
	electronic	B	0	0	0
	hardness testing	C	0	0	0
6	Secondary	A	0	0	0
	Calibration	B	0	0	0
	Laboratory	C	0	0	0
7	University:	A	0	0	0
	research	B	1	1	966
		C	0	0	0
	SUBTOTALS:	A	42	264	85,133
		B	12	25	14,849
		C	6	15	246
	GRAND TOTALS:	ABC	60	304	$100,228

Service Code	Type of Service	SP250 Number
A		
B	Irradiate Dosimeters	49010C
C	Supply Transfer Dosimeters	49020C & 49030C
	Special Measurements	49040S & 49050S

II. Neutron Interactions and Dosimetry Group

NEUTRON DOSIMETRY CALIBRATIONS FY 1990

Type of Service	Customer	SP 250	No. of Tests
Neutron Protection Instrumentation	AFRRI	N/A	2
	Arkansas P&L	44060C	1
	Baylor Medical	44060C	1
	Calvert Cliffs	44060C	10
	Carolina P&L	44060C	1
	Eberline Instrument Co.	44060C	1
	Illinois Power Co.	44060C	2
	Redstone Arsenal	44060C	4
	WPPSS	44060C	4
	NIH	44060C	2
	NSWC	N/A	8
	Pennsylvania Power	44060C	1
		Total	37
Neutron Source Calibration	Oak Ridge National Lab	44010C	2
	Battelle Pacific NW Lab	44010C	1
	Sandia Laboratory	44010C	2
	NAVALEX Laboratory	44010C	1
	Naval Research Laboratory	44010C	1
	Brookhaven National Lab	44010C	1
		Subtotal	8
	In-House (NIST) Sources	N/A	8
		Total	16

III. Radioactivity Group

RADIOACTIVITY CALIBRATIONS
August 1, 1989 to August 1, 1990

Category	Scheduled Calibrations		Non-Scheduled Tests	
	Number of Sources	Total Fee $	Number of Sources	Total Fee $
Alpha-Particle sources SP-250* Nos. 43030C	22	15,021	0	0
Beta-Particle Solutions and Gases (^{85}Kr)	--	--	3	4,405
Gamma-Ray Solutions, Point Sources, and Xe Isotopes	3	3,830	12	5,783
Totals	25	18,851	15	10,188

*SP-250 numbers refer to scheduled calibratons.

SPONSORED SEMINARS AND COLLOQUIA

Division 536, Ionizing Radiation

Ryuichi Tanaka, Japan Atomic Energy Research Institute, Japan, "JAERI AVF Cyclotron for Research on Radiation-Resistant Materials and Biotechnology," October 10, 1989.

Gary Kramer, Selected Activities of the Human Monitoring Laboratory: QA/QC for In-Vivo Monitoring and Environmental Dosimetry, Bureau of Radiation and Medical Devices, Ottawa, Canada, October 26, 1989.

Roger Scott, Scottish Universities Research and Reactor Center, East Kilbride, Glasgow, U.K., "Diffusion of Ground Water over Geological Time Periods," November 2, 1989.

John T. Lett, Department of Radiology & Radiation Biology, Colorado State University, "The Chemical Bases of Cellular Radiosensitivity to Ionizing Radiations," November 3, 1989.

Alan E. Friedman, Department of Chemistry, Columbia University, New York, NY, "Sequence Specific Binding of Transition Metal Complexes to DNA," November 8, 1989.

Raymond F. Borkman, School of Chemistry and Biochemistry, Georgia Institute of Technology, "Protein Photochemistry and Human Cataracts," November 17, 1989.

Carol Crannell, NASA Goddard Space Flight Center, Greenbelt, MD, "Imaging Solar Flares in Hard X-Rays and Gamma-Rays from High-Altitude Balloons Over the Antarctic," November 29, 1989.

Hans Conrad, North Carolina State University, Raleigh, NC, "Research on Electrorheological (ER) Fluids at NCSU," November 30, 1989.

David R. Ludlum, Department of Pharmocology, University of Massachusetts Medical School, "DNA Alkylation by Halonitrosoureas," December 1, 1989.

Peter Jean-Tone Lee, Department of Nuclear Engineering, Texas A&M University, Texas, "Dosimetry of Noble Gas Fission Products," December 7, 1989.

Roger W. Howell, Department of Radiology, Division of Radiation Research, University of Medicine and Dentistry, New Jeresy Medical School, University Heights, Newark, New Jeresy, "Track Structure and Dosimetry Techniques for Auger Emitters and Other Medical and Environmental Radionuclides," December 15, 1989

Matesh N. Varma, Office of Health & Environmental Research, U. S. Department of Energy, Washington, DC, "Radial Dose Distribution Measurements and Differences Between Condensed Phase and Gas Phase," January 4, 1990.

Division 536, Sponsored Seminars and Colloquia (cont'd)

Xianglin Shi, Visiting Professor, Chemistry Department, West Virginia University, "Free Radical Generation By Gluathione Reductase," January 24, 1990.

David F. Lewis, Electron Imaging Products, GAF Chemical Corporation, Wayne, New Jersey, "Processless Films for Imagery, Dosimetry, and Other Information Recording," February 8, 1990.

Stuart L. Belli, Vassar College, Poughkeepsie, NY, "Biosensor Research: Fluorescence Anisotropy as a Probe of Ion Carrier Mobility," March 19, 1990.

Henry T. Heaton, II, National Institute of Standards and Technology, Gaithersburg, Maryland, "The Status of National Measurement Quality Assurance Programs," April 16, 1990.

Catherine Hildebrand, Department of Pharmacology, University of Massachusetts, "The Chemistry of Purine Deoxyribonucleotides," April 18, 1990.

Sergio P. Ratti, Dipartimento di Fisica Nucleare e Teorica, Universita Degli Studi di Pavia, Pavia, Italy, "Analysis in Italy and France of the Air Radioactivity Data Consequent to the Chernobyl Accident and a Hint into Possible Fractal Models," April 30, 1990.

Jörg W. Müller, Bureau International des Poids et Mesures, Sèvres, France, "A Simple New Way of Separating True and Random Coincidences," May 18, 1990.

Kenneth Swinth, Battelle-Pacific Northwest Laboratories, Richland, Washington, "Performance Standards, Performance Tests and The Accreditation Process," June 7, 1990.

A. Wambersie, Radiobiology and Radiotherapy Unit, Catholic University of Louvain, University Clinics St. Luke, Brussels, Belgium, "From Progress in Accelerator Technology to Improvement in Radiation Therapy Results," June 20, 1990.

Alexi K. Pikaev, Director, Institute of Physical Chemistry, Academy of Sciences, USSR, "Dosimetry in Radiation Processing in the USSR," July 19, 1990.

Martyn C. R. Symons, University of Leicester, United Kingdom, "ESR Studies of Radiation Damage to DNA and the Effects of Additives," July 23, 1990.

Lu Ann Sidney, Industrial and Electronic Research Laboratory, 3M Company, St. Paul, Minnesota, August 31, 1990.

Etsuo Niki, Department of Reaction Chemistry, University of Tokyo, Japan, "Oxidation of LDL and Inhibition Mechanisms," September 13, 1990.

Division 536, Ionizing Radiation
Fundamental Neutron Measurements Program

In Fiscal Year 1990, the program on "Fundamental Neutron Measurements" reported on below was located in the Quantum Metrology Division of the Center for Atomic, Molecular, and Optical Physics. With the reorganization of NIST effective February 10, 1991, the program is relocated to the Neutron Interactions and Dosimetry Group of the Ionizing Radiation Division, Physics Laboratory. The technical activities for this program are included here since they are important to the future programs of the Ionizing Radiation Division.

FUNDAMENTAL NEUTRON MEASUREMENTS

This project concerns research activities in two distinct areas of low energy neutron physics. The first involves experimental work concerning neutron beta decay and weak interaction physics. An auxiliary activity related to this program concerns the development of new methods for the absolute determination of cold and thermal neutron fluxes. The second area involves the development of new facilities for investigations requiring advanced techniques in neutron optics and interferometry.

Much of the experimental work carried out to date was performed at remote facilities such as the Institut Laue Langevin. However, future work will be concentrated at the new National Cold Neutron Facility located adjacent to the NBSR. Indeed, developmental work and instrumentation of two of the experimental stations at this new facility is a responsibility of our group. One of these stations is a full flux "end guide" station for weak interaction studies and tests of fundamental symmetries. The other station is a monochromatic beam position with sophisticated environmental control for neutron interferometry.

Much of the work in this project is of a collaborative nature with strong involvement by U.S. national laboratories, U.S. and foreign universities and research laboratories abroad. Collaborating institutions include the University of Sussex (UK), Los Alamos National Laboratory, Harvard University, The Central Bureau for Nuclear Measurements (E.E.C. Geel,Belgium), Argonne National Laboratory and the Scottish Universities Research Reactor (Glasgow). Future projects now in the planning stage include collaborative efforts with the above institutions as well as the University of Michigan and the Kurchatov Institute of Nuclear Physics (Moscow, USSR). In addition to support from participating institutions, this program enjoys support from the Department of Energy, from the Science and Engineering Research Council (UK) and from N.A.T.O.

1. **Determination of the Neutron Lifetime** (M. S. Dewey, G. L. Greene, and D. M. Gilliam)

The beta decay lifetime of the free neutron is a quantity of considerable importance in the theory of weak interactions, in astrophysics and cosmology. An accurate value for the neutron lifetime is necessary for tests of the standard model of semileptonic weak interactions, for the calculation of the cosmic Helium abundance arising from the big bang, and for the calculation of a wide variety of stellar phenomenon including heavy element nucleosythesis, energy (and neutrino) production in the sun and supernova core collapse. This year saw the publication of our first experimental result from a multiyear program to determine this quantity. With an experimental error of approximately 0.5%,

this result is the most accurate ever for a measurement involving cold neutrons and is among the most accurate from all methods. This result was based on data collected at the Institut Laue Langevin in Grenoble. The experimental apparatus, with significant improvements, has now been installed at the CNRF.

2. **New Methods for Absolute Neutron Flux Determination** (M. S. Dewey, G. L. Greene, D. M. Gilliam and M. Arif)

As an outgrowth of the neutron lifetime project, two new methods for the accurate determination of thermal and cold neutron fluxes have been developed. The first is based on a "self calibrating" alpha-gamma coincidence method involving ^{10}Boron. The second involves a cryogenic calorimetric method employing ^{6}Li. Apparatus for the implementation of each of these schemes has been completed and initial tests are anticipated in early 1991. Both methods promise an accuracy approaching 0.1%. This would provide an approximately five fold improvement over current methods.

3. **Neutron Interferometry** (G. L. Greene and M. Arif)

One of the major experimental stations at the CNRF is an installation for neutron interferometry and advanced neutron optics. Significant progress has been made in the design of this facility over the past year. The primary focus of this work has involved considerations of the vibrational, thermal and acoustic isolation required for the very delicate experiments planned at this station. A detailed design of this isolation system has been completed and construction is underway.

INVITED TALKS

Division 536, Ionizing Radiation
Fundamental Neutron Measurements Program

Dewey, M. S., "Current Results and Future Prospects for a Neutron Lifetime Determination Using Trapped Protons," 7th International Symposium on Capture Gamma-Ray Spectroscopy, Asilomar, Pacific Grove, CA, October 17, 1990.

Dewey, M. S., "Status Report on the Gamma-Ray Component of a Determination of $N_A h/c$," 12th International Conference on Atomic Physics at the University of Michigan, July 19, 1990; Leningrad, USSR, October 24, 1989; Moscow, USSR, October 28, 1990.

Greene, G. L., Invited colloquium and seminar at the University of Washington, Seattle, WA, January 4, 1990.

Greene, G. L., Invited lecture at Xth Moriond Workshop on "New and Exotic Phenomena," Les Arcs, France, January 23, 1990.

Greene, G. L., Invited lecture at University of Delaware's Department of Physics and Astronomy, February 14, 1990.

Greene, G. L., Invited Colloquium, University of California, Berkeley, CA, May 22, 1990.

PUBLICATIONS

Division 536, Ionizing Radiation
Fundamental Neutron Measurements Program

Byrne, J., Dawber, P. G., Spain, J. A., Williams, A. P., Dewey, M. S., Gilliam, D. M., Greene, G. L., Lamaze, G. P., Scott, R. D., Pauwels, J., Eykens, R., and Lamberty, A., "Measurement of the Neutron Lifetime by Counting Trapped Protons," 65, 289 (1990).

Gilliam, D. M., Greene, G. L., and Lamaze, G. P., "Absolute Neutron Counting Based on ^{10}B Alpha Gamma Coincidence Methods," Nucl. Instr. Meth. A 284, 151 (1989).

Greene, G. L., "A Method for the Direct Determination of a Nuclear Transition Energy in Atomic Mass Units," Bull. Amer. Phys. Soc. 35, 1079 (1990).

Greene, G. L., "Determination of the Neutron Lifetime," Bull. Amer. Phys. Soc. 35, 924 (1990).

Lamberty, A., Eykens, R., Tagziria, H., Pauwels, J., DeBrievre, P.,
Scott, R. D., Byrne, J., Dawber, P. G., Gilliam, D. M. and Greene, G. L., "Recalibration of CBNM Reference Boron Deposits Used in the Measurement of the Neutron Lifetime," Nucl. Instrum. Meth. A 249, 393 (1990).

PUBLICATIONS IN PREPARATION

Division 536, Ionizing Radiation
Fundamental Neutron Measurements Program

Borner, H. G., Jolie, J., Hoyler, F., Robinson, S., Dewey, M. S., Greene, G., Kessler, E., and Deslattes, R. D., "Determination of Short Lifetimes with Ultra High Resolution (n,γ) Spectroscopy," submitted to Phys. Lett.

Dewey, M. S., "Current Results and Future Prospects for a Neutron Lifetime Determination Using Trapped Protons," in Proceedings of 7th International Symposium on Capture Gamma-Ray Spectroscopy (in press).

Greene, G. L., "Some Aspects of Fundamental Neutron Physics," to appear in New and Exotic Phenomena, Proceedings 1990 Recontre des Moriond, ed. T. Tranh.

Greene, G. L., Fischbach, E., and Hughes, R., "A New Test of Quantum Mechanics, Is Planck's Constant Unique?" Phys. Rev. Lett. (in press).

Kessler, E. G., Dewey, M. S., Greene, G. L., and Deslattes, R. D., "Precise Absolute Gamma-Ray Wavelength Measurements," in Proceedings of 7th International Symposium on Capture Gamma-Ray Spectroscopy (in press).

Layer, H. P., and Greene, G. L., "The Elastic Deformation of a Monolithic Perfect Crystal Interferometer: Implications for Gravitational Phase Shift Experiments," Phys. Lett.

Lieb, K. P., Börner, H. G., Dewey, M. S., Jolie, J., Robinson, S. J.,
Ulbig, S., and Winter, Ch., "Doppler Shift Attenuation Lifetime Measurements in ^{54}Cr Following Thermal Neutron Capture," Phys. Lett. B (in press).

Werner, S. A., Berliner, R., and Arif, M., "Incident Beam Coherence Effects in the Dynamical Diffraction of Neutrons," (in preparation).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 536, Ionizing Radiation
Fundamental Neutron Measurements Program

Geoffrey L. Greene

Member, National Steering Committee for the Advanced Neutron Source (1986 - present).

Program Committee for the Moriond Workshop on New and Exotic Phenomena (1990).

LIST OF ACRONYMS

AAMI	Association for the Advancement of Medical Instrumentation
AAPM	American Association of Physicists in Medicine
ACR	Absolute Cryogenic Radiometer
ADCL	Accredited Dosimetry Calibration Laboratories
ADMIT	analytical detection methods for the irradiation treatment of foods
AFRRI	Armed Forces Radiobiology Research Institute
ANS	American Nuclear Society
ANSI	American National Standards Institute
ANVIS	Aviator Night Vision Imaging System
AP	Tannular proton telescope
ARPES	Angle Resolved Photoelectron Spectroscopy Package
ASSI	Airglow Solar Spectrometer Instrument
ASTM	American Society for Testing and Materials
BB	Blackbody
BBU	Beam break-up
BIPM	Bureau International des Poids et Mesures
BRDF	Bidirectional Reflectance Distribution Function
BSDF	Bidirectional Scattering Distribution Function
BTI	Bubble Technology, Inc.
CAD	Computer-aided Design
CAM	Computer-aided Manufacturing
CAMAC	Computer Automated Measurement and Control
CAST	Council of Agricultural Science and Technology
CCD	charged coupled device
CCE	Consultative Committee on Electricity
CCEMRI	Consultative Committee for Ionizing Radiations
CCG	Calibration Coordination Group
CCPR	Consultative Committee on Photometry and Radiometry
CEBAF	Continuous Electron Beam Accelerator Facility
CERN	European Center for Nuclear Research
CIE	Commission Internationale De L'Eclairage
CIRRPC	Committee on Interagency Radiation Research and Policy Coordination
CNRF	Cold Neutron Research Facility
CORM	Council for Optical Radiation Measursements
COTR	Contracting Officer's Technical Representative
CRR	Center for Radiation Research
CSDA	continuous slowing-down approximation
CSEWG	Cross Section Evaluation Working Group
CSI	Compton scatter imaging
cw	Continuous wave
DNA	deoxyribose nucleic acid
DoD	Department of Defense

Acronyms (cont'd)

DOE	Department of Energy
DRIP	Detector Response Intercomparison Program
ENDF	Evaluated Nuclear Data File
ENDL	Evaluated Nuclear Data Library
ENSDF	Evaluated Nuclear Structure Data File
EPA	Environmental Protection Agency
ES	Relectron spin resonance
ESR	Electrical Substitution Radiometer
FAA	Federal Aviation Administration
FAD	FASCAL Accurate Detector
FASCAL	Facility for Automatic Spectroradiometric Calibrations
FDA	Food and Drug Administration
FEA	Finite - Element - Analysis
FEL	Free Electron Laser
FEMA	Federal Emergency Management Agency
FIMS	fissionable isotope mass standards
FLIR	Forward Looking Infrared Radiometer
FRG	Federal Republic of Germany
FT	Fourier Transform
FT	Fourier Transform Infrared
FTIR	Fourier transfer infrared
FY	Fiscal Year
GPIB	General Purpose Instrumentation Bus
GRT	Germanium Resistance Thermometers
H	Hungary
HACR	High Accuracy Cryogenic Radiometer
HDL	Harry Diamond Laboratories
HFIR	High Flux Isotope Reactor
HSST	heavy section steel technology
IAEA	International Atomic Energy Agency
ICRM	International Committee for Radionuclide Metrology
ICRU	International Commission on Radiation Unite and Measurements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IPSN	Institut de Protection et de Sureté Nucleairé
IPTS	International Practical Temperature Scale
IR	Infrared
ISCC	Inter-Society Color Council
ISO	International Standards Organization
ITS	International Temperature Scale
IUCr	International Union of Crystallography
LANL	Los Alamos National Laboratory
LBIR	Low Background Infrared Radiometry
LBL	Lawrence Berkeley Laboratory
LBRS	Low Background Reference System
LET	linear energy transfer

Acronyms (cont'd)

LLNL	Lawrence Livermore National Laboratory
LS	liquid scintillation
MARS	Multiple-Angle Reference System
MCNP	Monte Carlo Neutron Photon (computer code)
MEA	Materials Engineering Associates
MET	medium energy telescope
MIDAS	Modular Interactive Data Acquisition System
MIRD	Medical Internal Radiation Dose (committee)
MODIL	Manufacturing Operations Development & Integration Laboratory
MRT	Minimal Resolvable Temperature
NAS	National Academy of Sciences
NASA	National Aeronautical and Space Administration
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NDT	nondestructive testing
NEANDC	Nuclear Energy Agency Nuclear Data Committee
NED	Nuclear Effects Directorate
NIM	Nuclear Instrumentation Module
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NOAA	National Oceanographic Atmospheric Administration
NOBCChe	National Organization for the Professional Advancement of Black Chemists and Chemical Engineers
NORA	non-overlapping redundant array
NPL	National Physical Laboratory (U. K.)
NRC	National Research Council
NRC	Nuclear Regulatory Commission
NRL	Naval Research Laboratory
NVIS	Night Vision Imaging System
NVLAP	National Voluntary Laboratory Accreditation Program
NVS	National Voluntary Standards
ORM	Office of Radiation Measurement
ORNL	Oak Ridge National Laboratory
PC	Personal Computer
PTB	Physikalisch-Technische Bundesanstalt (Germany)
PTFE	Polytetrafluoroethylene
PWR	pressurized-water reactor
PWS	Primary Working Standards
QED	Quantum Efficient Device
RBE	relative biological efficiency
rf	Radio frequency
RF	Radio Frequency
rms	Root-mean-square
RTM	Racetrack Microtron
SAIC	Science Applications International Corporation
SDIO	Strategic Defense Initiative Organization

Acronyms (cont'd)

SEBA	Standards' Employees Benefit Association
SOLSPEC	Solar Spectrometer
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPIE	Society of Photo Optical Instrumentation Engineers
SPIE	International Society for Optical Engineering
SRM	Standard Reference Material
SSBUV	Shuttle Solar Backscatter UV Radiometer
SSTR	solid state track recorder
SURF	Synchrotron Ultraviolet Radiation Facility
SUSIM	Solar UV Spectral Irradiance Monitor
TCAP	time-correlated associated particle
TEPC	tissue equivalent proportional counter
TLD	thermoluminescent detector
UK	United Kingdom
USA	United States of America
USAIDR	U.S. Army Institute of Dental Research
USCEA	U.S. Council for Energy Awareness
USDA	United States Department of Agriculture
USNA	U.S. Naval Academy
USSR	Union of Socialist Soviet Republic
UV	Ultraviolet
UV-B	Ultraviolet-B
VIS	Visible
VNIIOF	All-Union Research Institute for Optical and Physical Measurements
WAFAC	wide-angle free-air chamber
WHO	World Health Organization
XRF	x-ray fluorescence

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This report summarizes research projects, measurement method development, calibration and testing and data evaluation activities that were carried out during Fiscal Year 1990 in the NIST Center for Radiation Research. These activities fall in the areas of radiometric physics, radiation sources and instrumentation, and ionizing radiation.

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